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(54) **GENERATION OF COLOR IMAGES USING WHITE LIGHT AS SOURCE**

(71) Applicant: **LUMUS LTD.**, Nes Ziona (IL)

(72) Inventors: **Eitan Ronen**, Rechovot (IL); **Ronen Chriki**, Lod (IL); **Jonathan Gelberg**, Modiin (IL)

(73) Assignee: **LUMUS LTD.**, Nes Ziona (IL)

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(52) **U.S. Cl.**

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(Continued)

(58) **Field of Classification Search**

None
See application file for complete search history.

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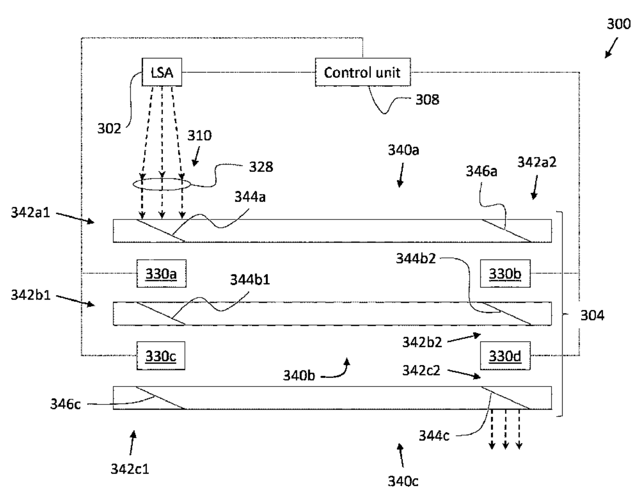
Primary Examiner — Amare Mengistu
Assistant Examiner — Sarvesh J Nadkarni
(74) *Attorney, Agent, or Firm* — The Roy Gross Law Firm, LLC; Roy Gross

(57) **ABSTRACT**

Disclosed herein is an optical assembly for generating a color image using white light as source. The optical assembly includes a broadband white light source array, a color filter assembly configured to allow selectively filtering therethrough light in each of three additive primary colors, and a control unit. The control unit is configured to actuate light sources in the light source array according to three intensity maps. Each of the intensity maps corresponds to one of the three additive primary colors. The control unit is further configured to synchronize operations of the light source array and the color filter arrangement such that, when light sources in the light source array are actuated according to one of the three intensity maps, the color filter arrangement filters therethrough light at the additive primary color to which the intensity map corresponds.

19 Claims, 9 Drawing Sheets



(51) **Int. Cl.**
G09G 3/00 (2006.01)
G09G 3/34 (2006.01)

(52) **U.S. Cl.**
CPC ***G09G 3/001*** (2013.01); ***G09G 3/3426*** (2013.01); *G02B 2027/0114* (2013.01); *G09G 2320/0233* (2013.01); *G09G 2340/12* (2013.01)

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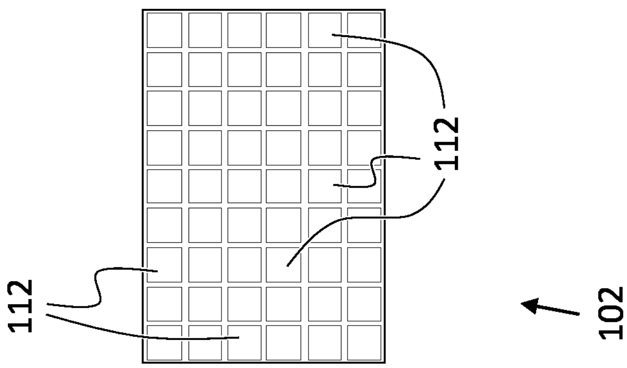
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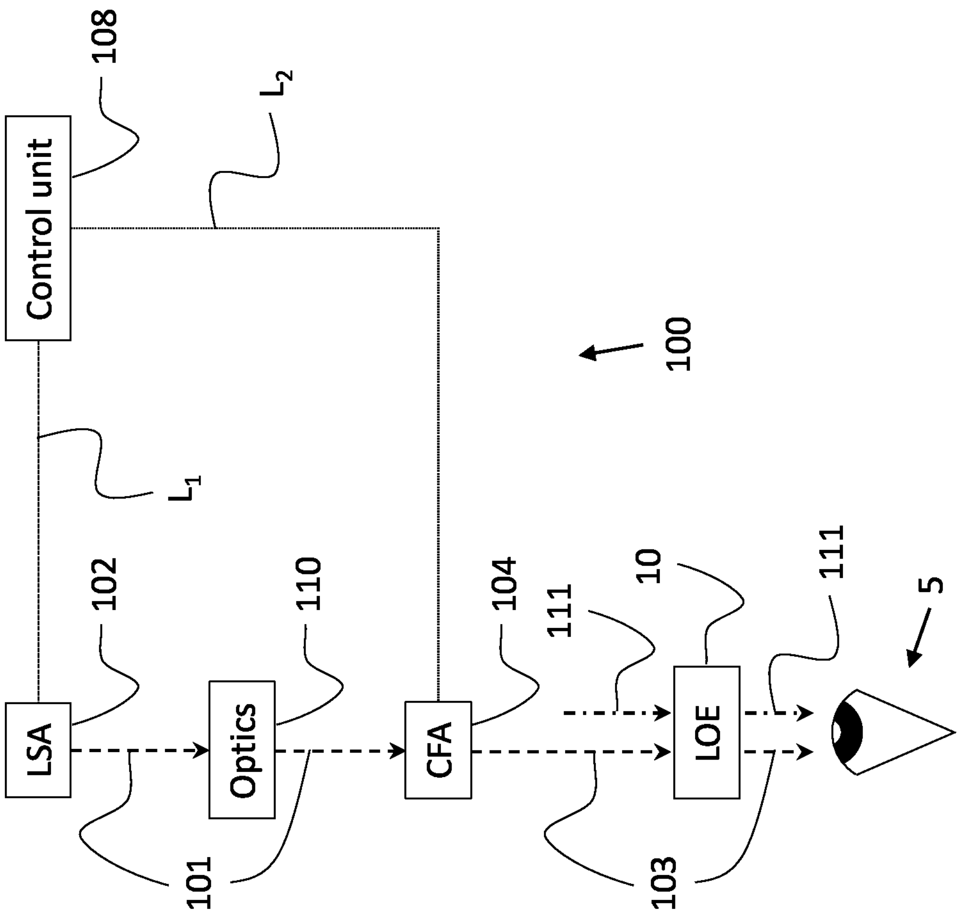
Fig. 1B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108
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L_1
LSA
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Optics
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CFA
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111
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LOE
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5
101
103

Fig. 1A

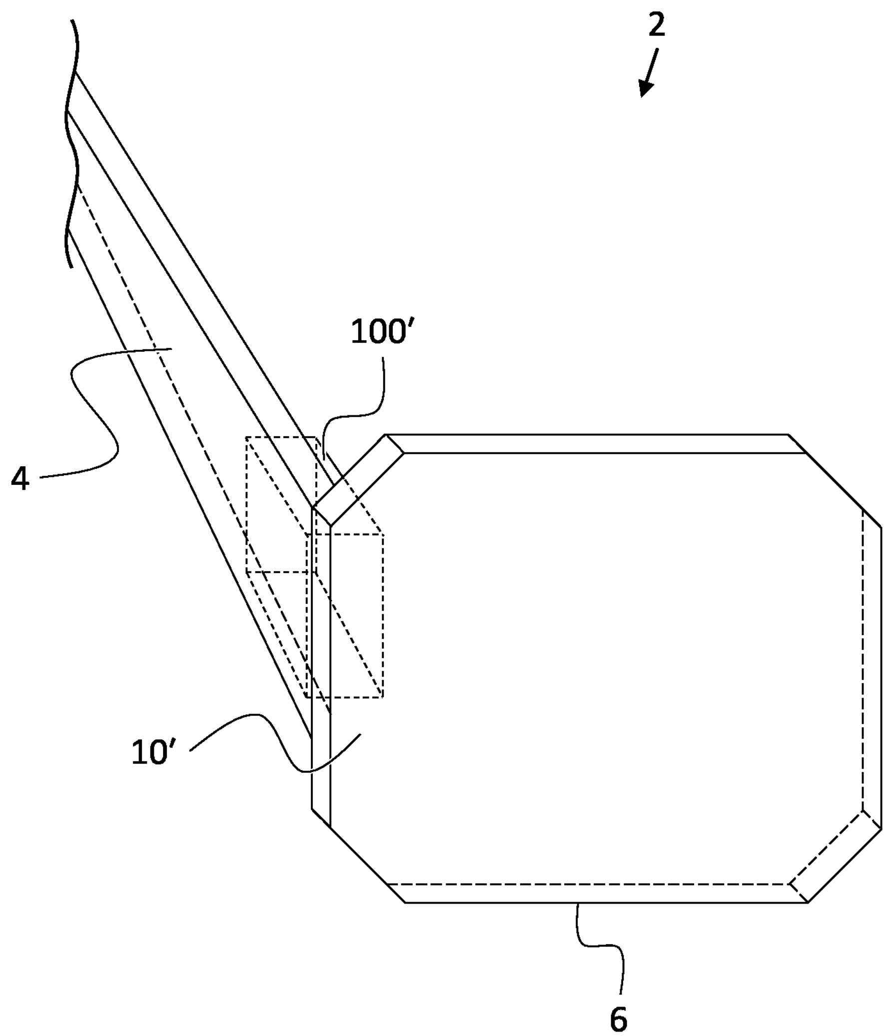
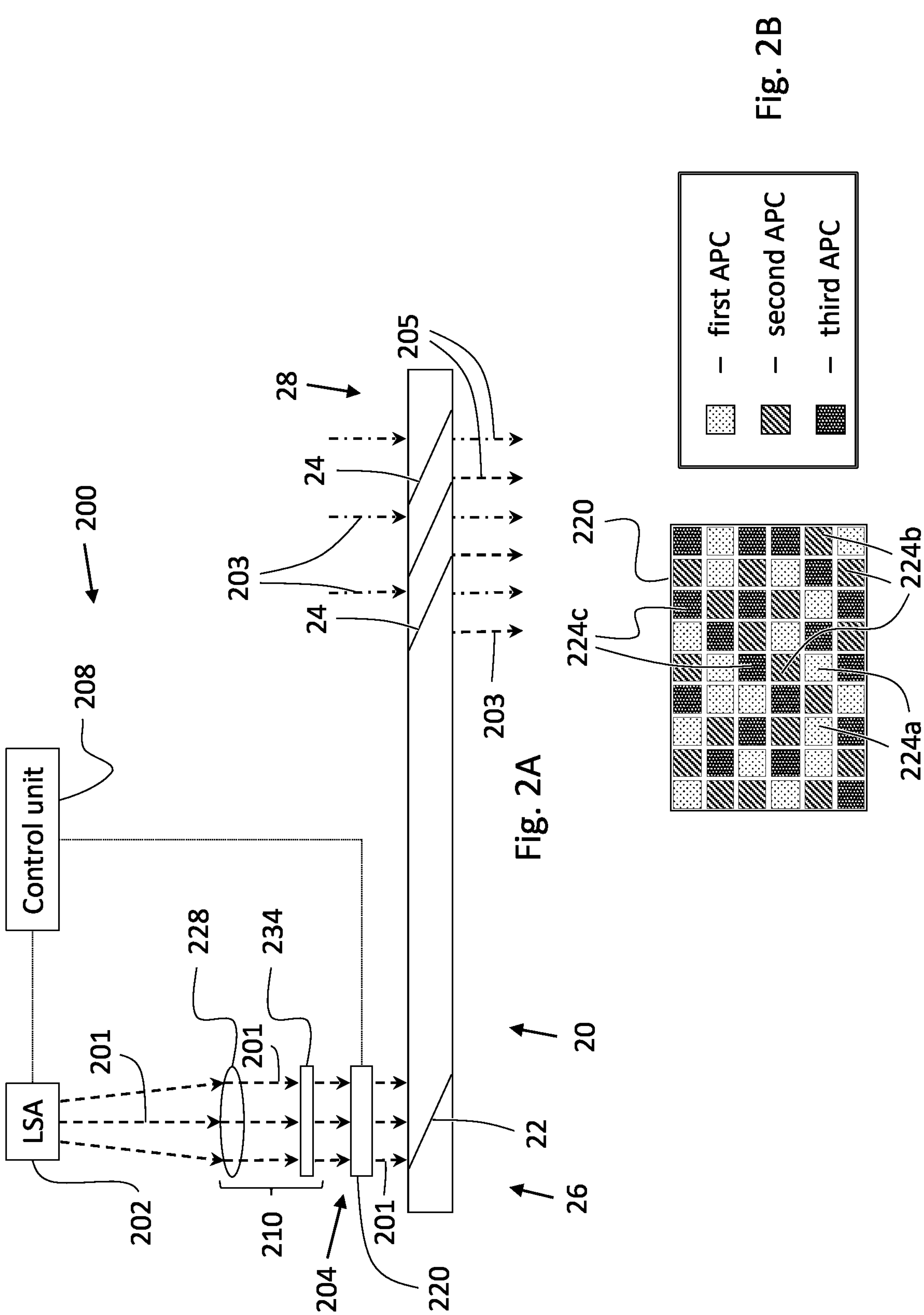


Fig. 1C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first APC
second APC
third APC
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202
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20
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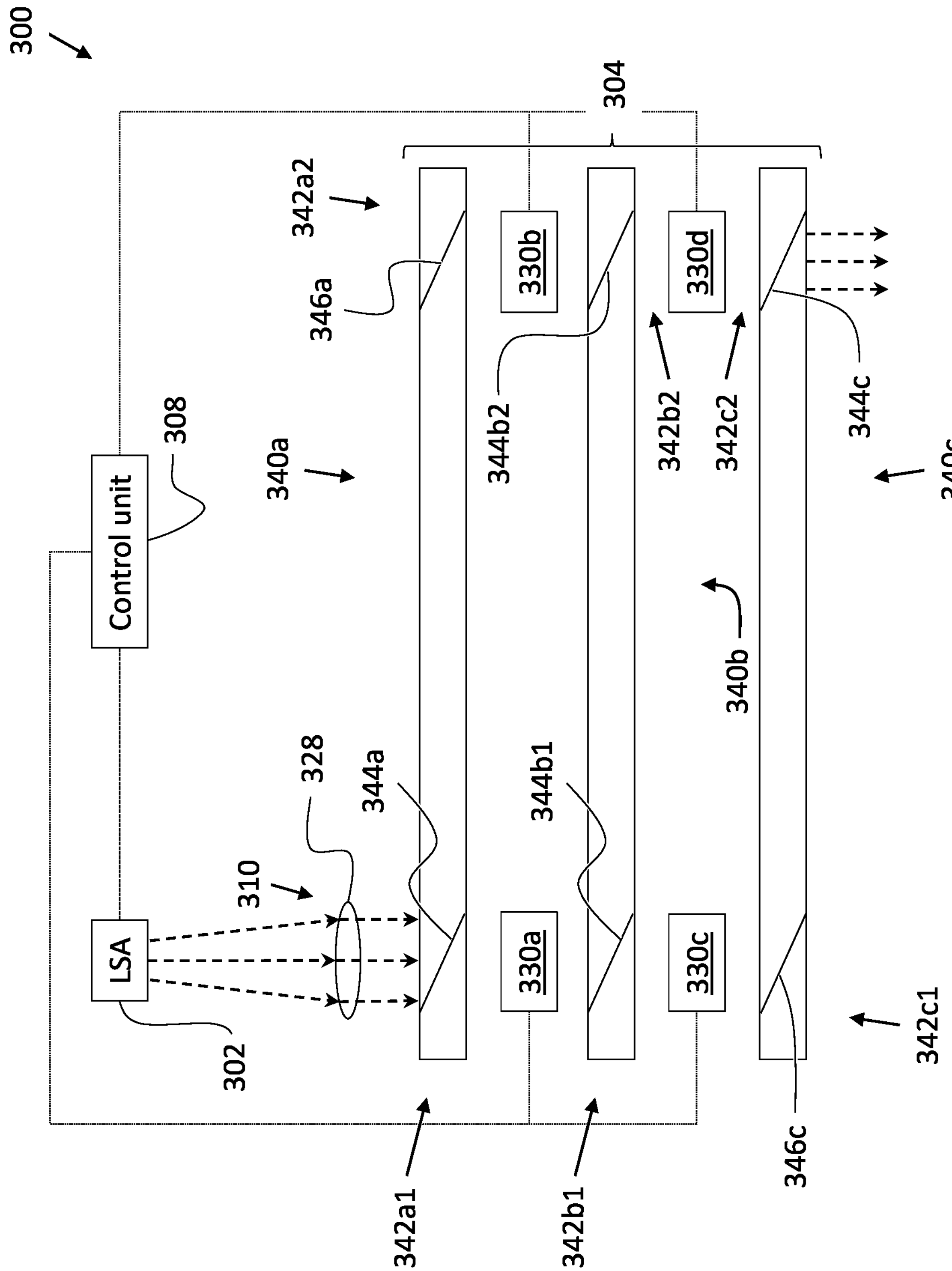
224b
224c

Fig. 2A

Fig. 2B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346a
330b
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342c2
344c
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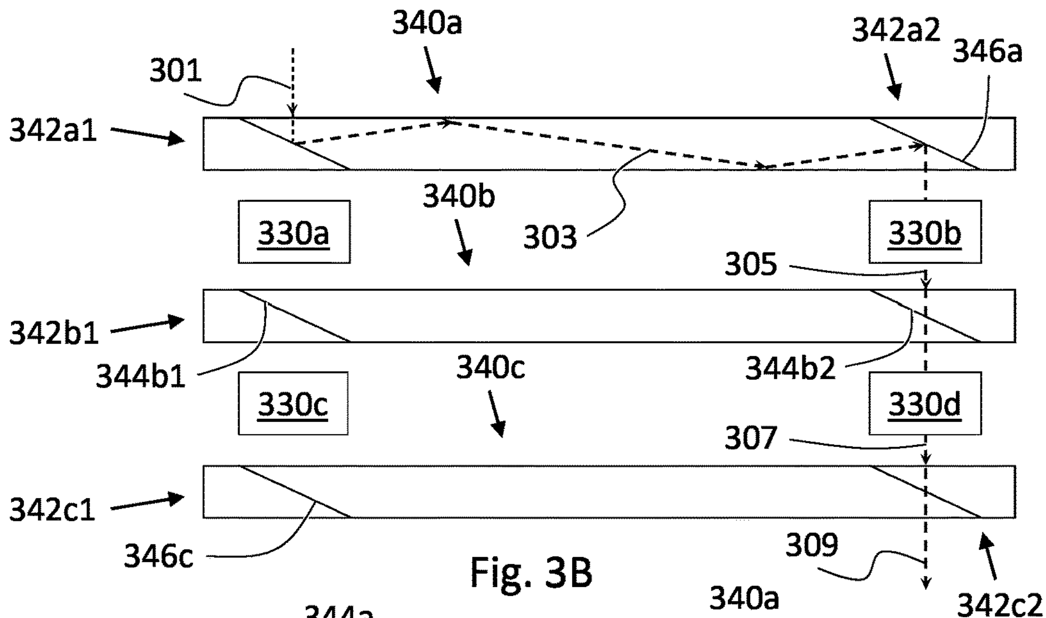
330c
302
342a1
342b1
346c
342c1

Fig. 3A



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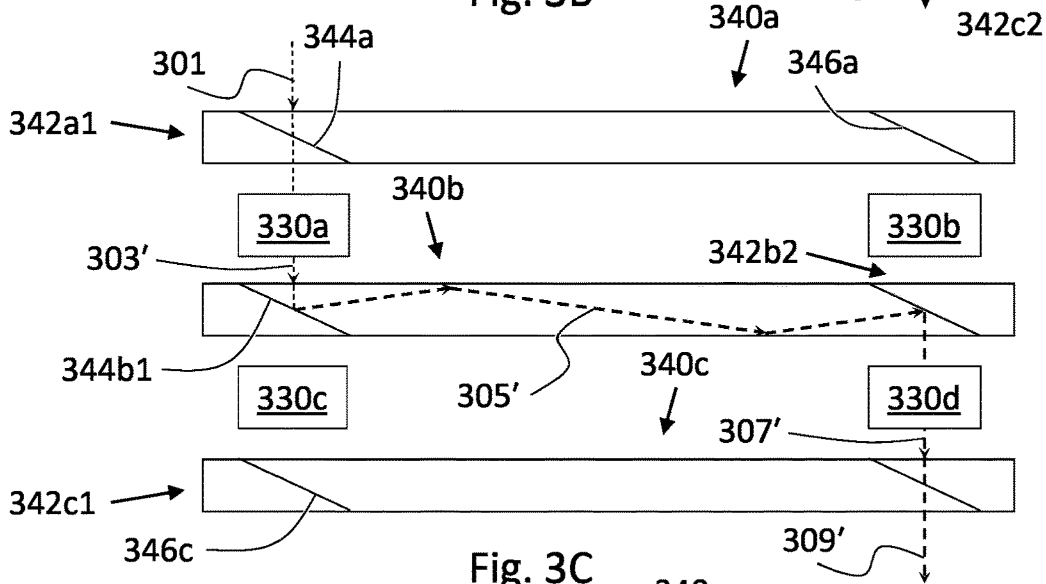


Fig. 3C

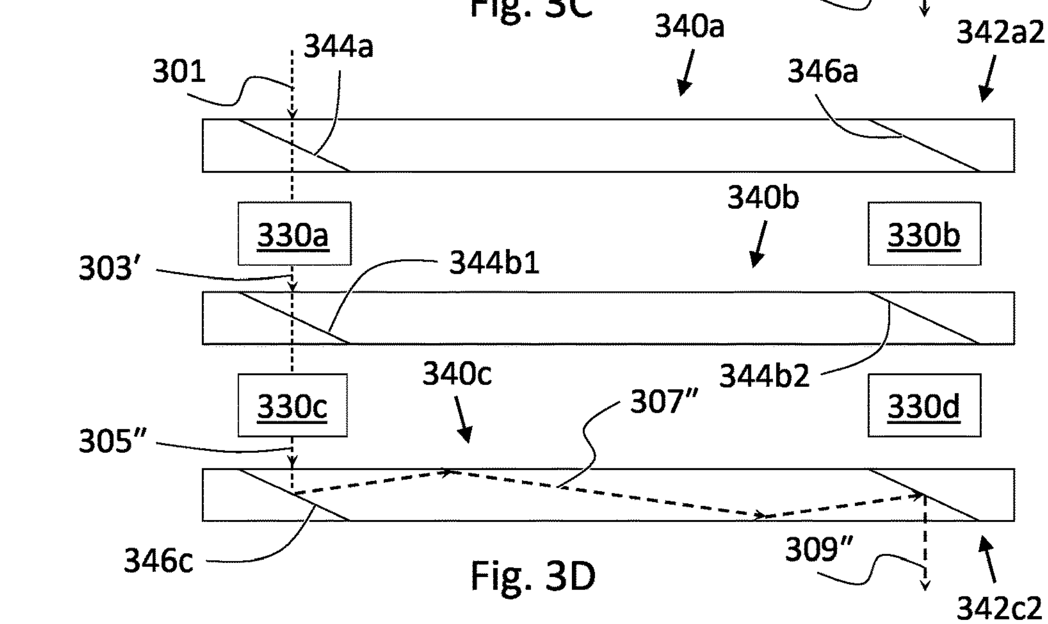
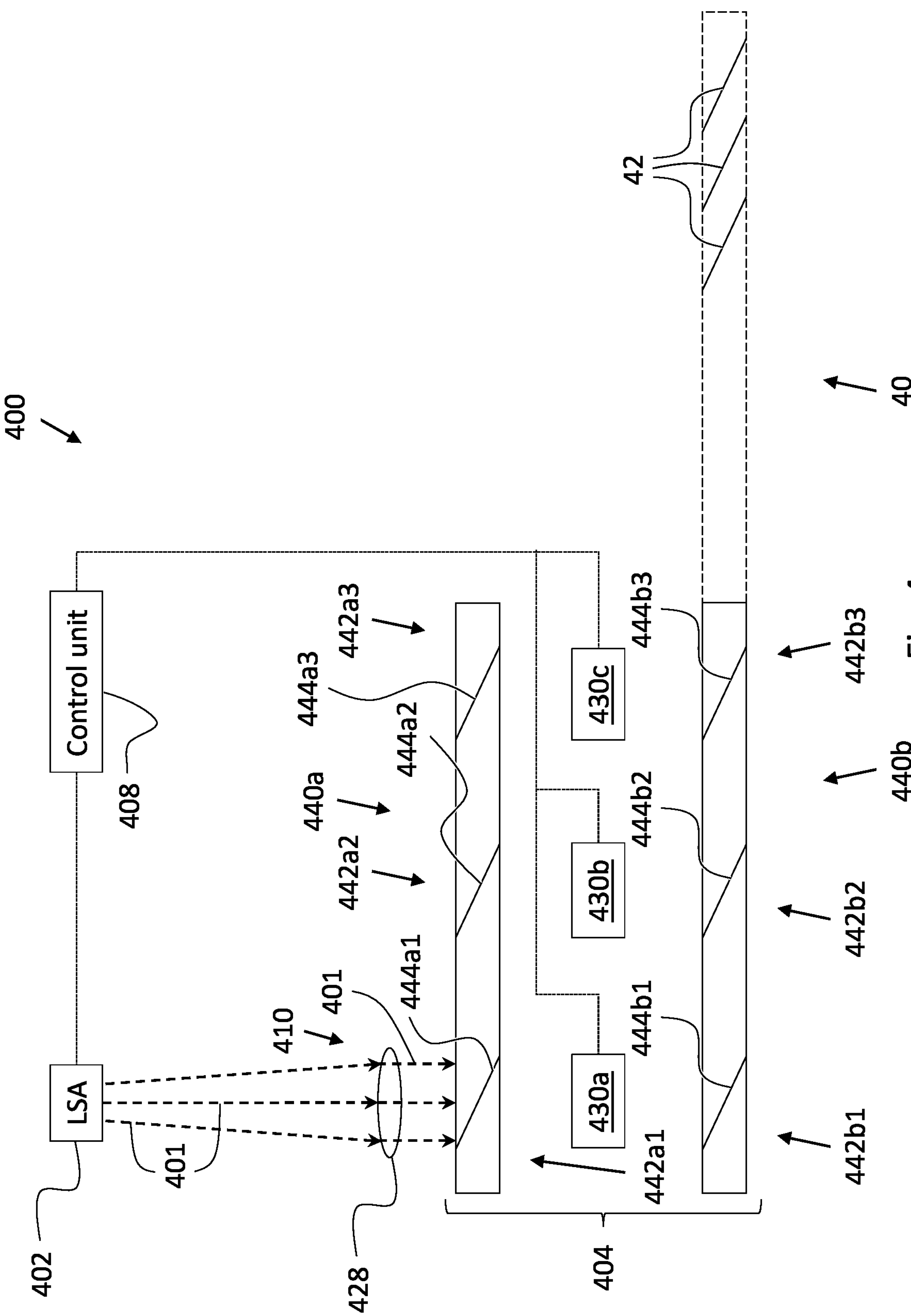


Fig. 3D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408
LSA
402
401
401
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442a3
430b
430c
404
444b1
444b2
444b3
442b1
442b2
442b3
440b
40
42

Fig. 4

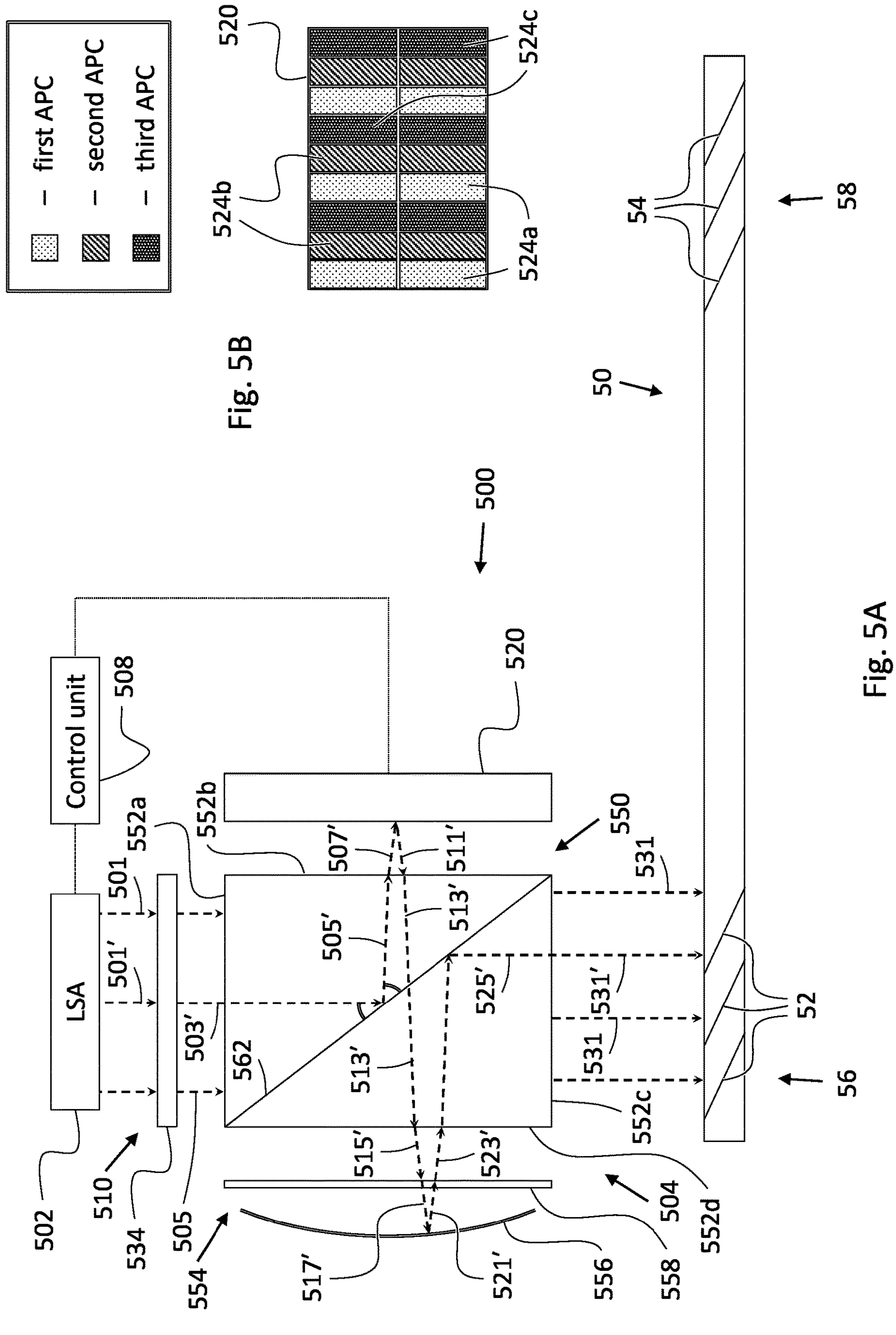
first APC
second APC
third APC
520
524a
524b
524c
LSA
Control unit
502
508
510
534
505
501
501'
503'
505'
507'
511'
513'
515'
517'
521'
523'
525'
531
531'
552a
552b
552c
552d
550
554
556
558
562
504
500
50
52
54
56
58

Fig. 5B

Fig. 5A

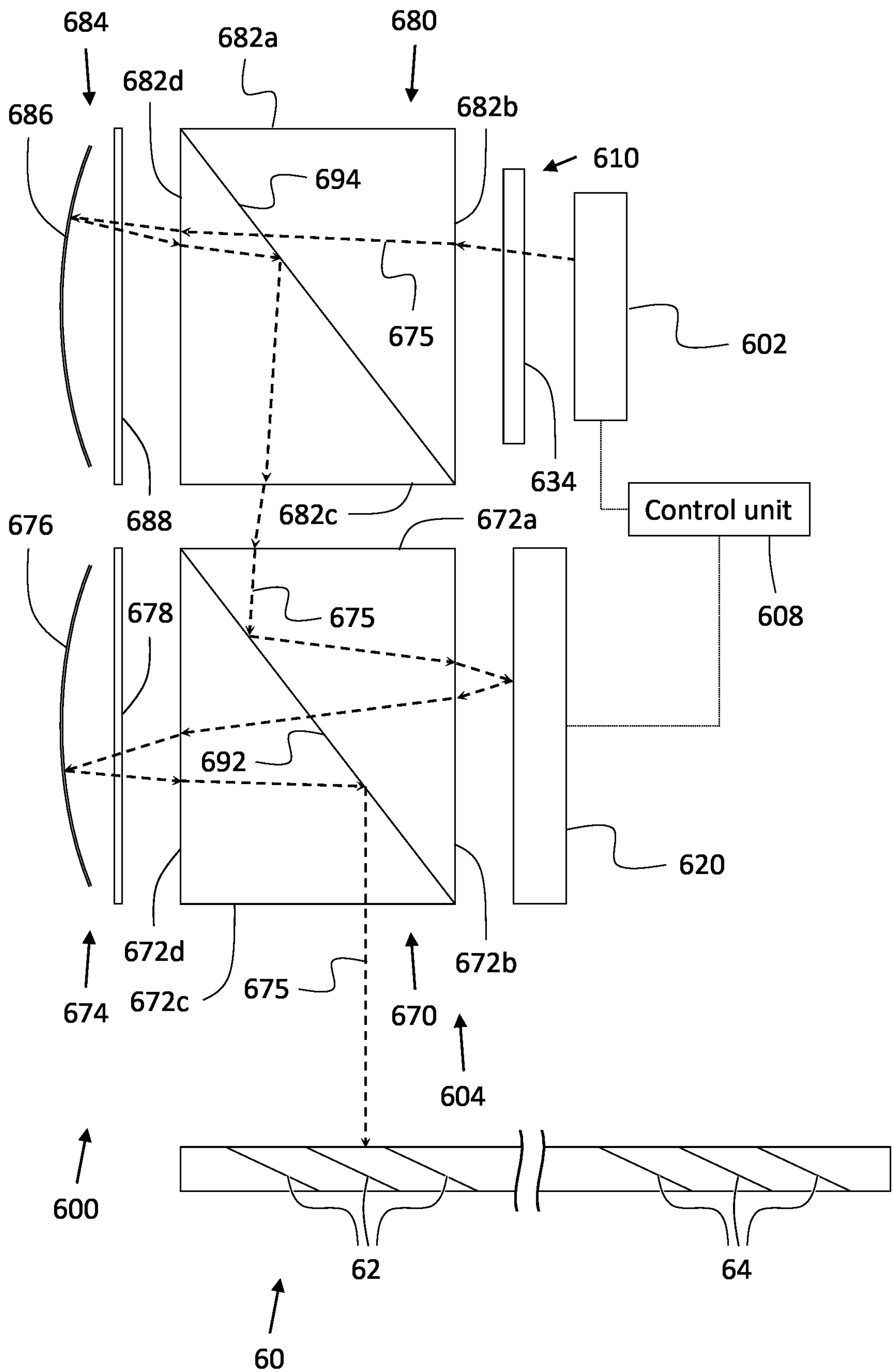
684
682a
680
682d
686
682b
610
694
675
602
634
Control unit
688
682c
676
672a
678
608
675
692
620
672d
672b
674
672c
675
670
604
600
62
64
60

Fig. 6

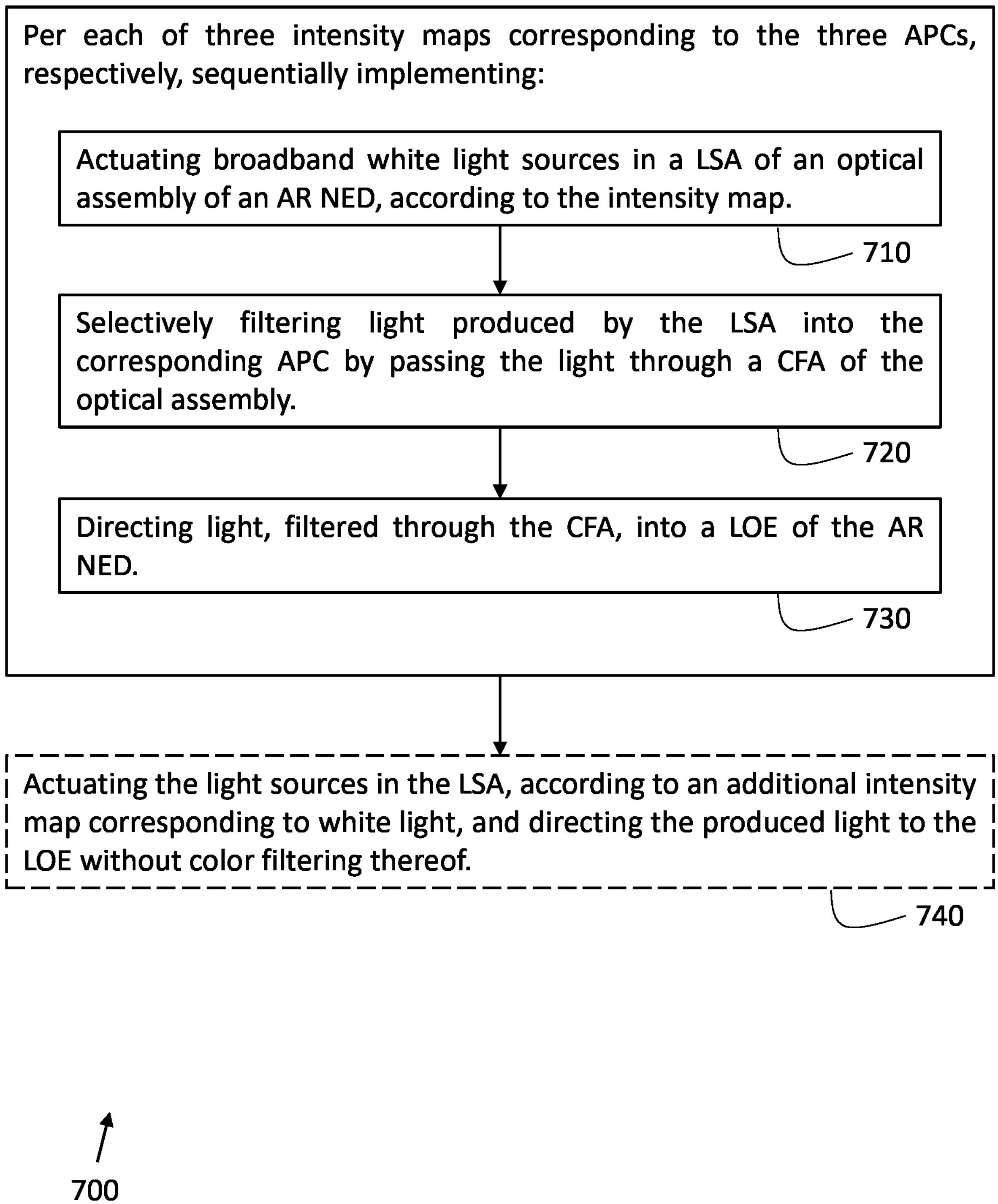
Per each of three intensity maps corresponding to the three APCs, respectively, sequentially implementing:
Actuating broadband white light sources in a LSA of an optical assembly of an AR NED, according to the intensity map.
710
Selectively filtering light produced by the LSA into the corresponding APC by passing the light through a CFA of the optical assembly.
720
Directing light, filtered through the CFA, into a LOE of the AR NED.
730
Actuating the light sources in the LSA, according to an additional intensity map corresponding to white light, and directing the produced light to the LOE without color filtering thereof.
740
700

Fig. 7

GENERATION OF COLOR IMAGES USING WHITE LIGHT AS SOURCE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a National Phase of PCT Patent Application No. PCT/IL2021/051039 having International filing date of 24 Aug. 2021, which claims the benefit of priority of U.S. Provisional Patent Application No. 63/070,564, filed 26 Aug. 2020, the contents of which are all incorporated herein by reference in their entirety.

TECHNICAL FIELD

The present disclosure relates generally to production of color images using white light as source.

BACKGROUND

Augmented reality (AR) near-eye displays (NEDs)—also referred to as (AR) head-mounted displays or (AR) wearable displays—integrate a projected virtual (digital) image into the field-of-view of the wearer. Since the virtual images are comparatively small, typically, self-emissive displays are preferred, being highly-efficient in terms of power consumption. In principle, a light emitting diode (LED) array including three groups of LEDs, configured to generate red, green, and blue light, may be employed to provide illumination. However, due to limitations on the dimensions of state-of-the-art color LEDs, producing uniform virtual color images (using color LEDs) remains a challenge.

SUMMARY

Aspects of the disclosure, according to some embodiments thereof, relate to production of color images using white light as source. More specifically, but not exclusively, aspects of the disclosure, according to some embodiments thereof, relate to color image production in augmented reality near eye displays using broadband white light as source.

Thus, according to an aspect of some embodiments, there is provided an optical assembly for generating a color image using white light as source. The optical assembly includes:

A light source array (LSA) including a plurality of broadband white light sources.

A color filter assembly (CFA) configured to allow selectively filtering therethrough light in each of three additive primary colors (APCs).

A control unit.

The control unit is configured to actuate light sources in the LSA according to three intensity maps. Each of the intensity maps corresponding to one of the APCs. The control unit is further configured to synchronize operations of the LSA and the CFA such that, when light sources in the LSA are actuated according to an intensity map corresponding to one of the APCs, the CFA filters therethrough light in the corresponding APC.

According to some embodiments of the optical assembly, the LSA is a LED array.

According to some embodiments of the optical assembly, the LED array is an inorganic micro-LED (mLED) array or an organic LED (OLED) array.

According to some embodiments of the optical assembly, the CFA includes a liquid crystal display (LCD) array. Each cell in the LCD array corresponds to one of the three APCs, respectively. Cells corresponding to the same APC are jointly on and off switchable by the control unit, such that: (i) when switched on, each of the cells filters therethrough light in the corresponding APC, and (ii) when switched off, each of the cells blocks all light impinging thereon. The optical assembly further includes a linear polarizer configured to polarize the light generated by the LSA.

According to some embodiments of the optical assembly, the CFA includes at least three color filters, individually on and off switchable by the control unit. At least one of the color filters is configured to, when switched on, filter therethrough light in a respective APC from the three APCs, and, when switched off, block all light arriving thereat, and/or at least one of the color filters is configured to, when switched on, block light in a respective APC from the three APCs, and, when switched off, block all light arriving thereat. The control unit is configured to collectively switch the at least three color filters between three transmission modes, such that in each transmission mode light in a respective APC from the three APCs is filtered through the CFA.

According to some embodiments of the optical assembly, the at least three color filters include a first color filter, a second color filter, and a third color filter configured to filter therethrough light in only one of the three APCs, respectively. The CFA further includes a first waveguide, configured to have transmitted thereinto light generated by the LSA, a second waveguide, and at least three dichroic mirrors. Each of the dichroic mirrors is configured to reflect or filter light in a respective APC from the three APCs. The first, second, and third color filters are disposed between the waveguides. Each of the dichroic mirrors is embedded within one of the waveguides, such that (i) light generated by the LSA, and incident on a dichroic mirror, embedded in the first waveguide, is either directed thereby onto a respective one of the first, second, and third color filters or onto an adjacent dichroic mirror in the first waveguide, and (ii) light filtered through any of the first, second, and third color filters, and incident on a dichroic mirror, embedded in the second waveguide, is reflected inside the second waveguide.

According to some embodiments of the optical assembly, the at least three dichroic mirrors include six dichroic mirrors. A first dichroic mirror, a second dichroic mirror, and a third dichroic mirror are embedded in a first side-portion, a central portion, and a second side-portion of the first waveguide, respectively. The central portion of the first waveguide is disposed between the first and second side-portions of the first waveguide. A fourth dichroic mirror, a fifth dichroic mirror, and a sixth dichroic mirror are embedded in a first side-portion, a central portion, and a second side-portion of the second waveguide, respectively. The central portion of the second waveguide is disposed between the first and second side-portions of the second waveguide. The first, second, and third color filters are disposed between the first side-portions, the central portions, and the second side-portions, respectively. The first, second, and third color filters and the dichroic mirrors are configured such that when only the first color filter, only the second color filter, and only the third color filter, is switched on, light, generated by the LSA, and incident on the first side-portion of the first waveguide, is filtered into the first, second, and third APCs, respectively, and is output at the second side-portion of the second waveguide.

According to some embodiments of the optical assembly, at least one of the at least three color filters includes a respective filter component and a respective shutter. The filter component is configured to transmit light only in the corresponding APC. Each shutter is configured to be controllably opened and closed at command from the control unit, such that, when closed, the shutter prevents light from arriving at the respective filter component or blocks light transmitted through the respective filter component.

According to some embodiments of the optical assembly, at least one of the shutters is an LCD panel, configured to be actuated by the control unit. The optical assembly further includes a linear polarizer configured to polarize the light generated by the LSA.

According to some embodiments, at least one of the shutters is a mechanical shutter.

According to some embodiments of the optical assembly, the CFA further includes a first waveguide, a second waveguide, and a third waveguide, which are adjacently and successively disposed. The first waveguide has embedded, in a first side-portion thereof, a first beam splitting component, and, at a second side-portion thereof, a first mirror. The second waveguide has embedded, in a first side-portion thereof, a second beam splitting component, and, at a second side-portion thereof, a third beam splitting component. The third waveguide has embedded, in a first side-portion thereof, a second mirror, and, at a second side-portion thereof, a fourth beam splitting component. The first waveguide is configured to receive thereinto, at the first side-portion thereof, light generated by the LSA. The third waveguide is configured to output, from the second side-portion thereof, light received thereinto.

According to some embodiments of the optical assembly, the beam splitting component is a dichroic mirror, a diffraction grating, or a dielectric beam splitter.

According to some embodiments of the optical assembly, the at least three color filters include four color filters. A first color filter is disposed between the first side-portion of the first waveguide and the first side-portion of the second waveguide, or embedded within the first side-portion of the first waveguide. A second color filter is disposed between the second side-portion of the first waveguide and the second side-portion of the second waveguide, or embedded within the second side-portion of the first waveguide. A third color filter is disposed between the first side-portion of the second waveguide and the first side-portion of the third waveguide, or embedded within the first side-portion of the second waveguide. A fourth color filter being disposed between the second side-portion of the second waveguide and the second side-portion of the third waveguide, or embedded within the second side-portion of the first waveguide. APC filtering properties of each of the color filters, positionings thereof, and actuation times, are such that the first waveguide propagates there across light only in the first APC, the second waveguide propagates there across light only in the second APC, and the third waveguide propagates there across light only in the third APC.

According to some embodiments of the optical assembly, (i) when switched on, the first color filter blocks only light in the first APC, (ii) when switched on, the second color filter filters therethrough only light in the first APC, (iii) when switched on, the third color filter filters therethrough only light in the second APC, and (iv) when switched on, the fourth color filter blocks only light in the second APC.

According to some embodiments of the optical assembly, the optical assembly further includes optics configured to direct light from the LSA onto the CFA.

According to some embodiments of the optical assembly, the optics includes one or more lenses configured to collimate light generated by the LSA.

According to some embodiments of the optical assembly, the CFA includes a liquid crystal on silicon (LCoS) array. Each cell in the LCoS array includes sub-cells corresponding to each of the three APCs, respectively. The LCoS array is switchable between three reflection modes corresponding to the three APCs, such that in each reflection mode, each sub-cell corresponding to the APC reflects light in the APC at a reflection level dictated by the control unit and the rest of the sub-cells are switched off. The light generated by the LSA is linearly polarized and/or wherein the optical assembly further includes a linear polarizer.

According to some embodiments of the optical assembly, each of the light sources in the LSA is configured to illuminate at least one cell from the cells in the LCoS array.

According to some embodiments of the optical assembly, the optical assembly is configured such that substantially every cell in the LCoS array is positioned to receive light substantially only from the respective light source in the LSA.

According to some embodiments of the optical assembly, the CFA further includes a first polarizing beam splitter (PBS) and first collimating optics. The first PBS is configured to reflect polarized light, generated by the LSA or filtered through the polarization filter, towards the LCoS array. The first collimating optics is configured to collimate the reflected polarized light arriving thereat via the first PBS. The CFA is configured such that the collimated light is next indirectly output, having passed again through the first PBS, or directly output (i.e. without repassage via the first PBS), such as to be imaged on the LCoS array.

According to some embodiments of the optical assembly, the first collimating optics includes a collimating mirror arrangement (which may include one or more curved mirrors and lenses and/or Fresnel lenses). The CFA is configured such that the collimated light is indirectly output having passed again through the first PBS. The CFA further includes a quarter waveplate positioned between the first PBS and the collimating mirror arrangement, such that the on reentry to the first PBS, the polarization of the light has been rotated by 90°.

According to some embodiments of the optical assembly, the optical assembly further includes a second PBS and second collimating optics, wherein light generated by the LSA is first passed through the second PBS, collimated by the second collimating optics, and directly or indirectly propagated therefrom into the first PBS, such as to be imaged on the LCoS array.

According to some embodiments of the optical assembly, the control unit is configured to send to the LCoS array three additional intensity maps corresponding to the three APCs, respectively. The three additional intensity maps are of higher resolution than the intensity maps according to which the LSA is actuated. Each intensity map, according to which the LSA is actuated, and a respective one of the three additional intensity maps, sent to the LCoS array, which corresponds to the same APC, in combination reproduce an intensity map associated with the corresponding APC, as specified by a color bitmap stored in the control unit.

According to some embodiments of the optical assembly, the CFA includes a first filter, a second filter, and a third filter, which are individually openable and closeable by the controller. Each filter is configured to transmit all light incident thereon when open, and block all light incident thereon when closed. The CFA further includes a first waveguide, configured to have transmitted thereinto light generated by the LSA, a second waveguide, and at least three dichroic mirrors. Each of the dichroic mirrors is configured to reflect or filter light in a respective APC from the three APCs. The three filters (i.e. the first, second, and third filters) are disposed between the waveguides. Each of the dichroic mirrors is embedded within one of the waveguides, such that: (i) light generated by the LSA, and incident on a dichroic mirror, embedded in the first waveguide, is either directed thereby onto a respective one of the three filters or onto an adjacent dichroic mirror in the first waveguide, and (ii) light filtered through any of the three filters and incident on a dichroic mirror, embedded in the second waveguide, is reflected inside the second waveguide.

According to some embodiments of the optical assembly, the at least three dichroic mirrors include six dichroic mirrors. A first dichroic mirror, a second dichroic mirror, and a third dichroic mirror, are embedded in a first side-portion, a central portion, and a second side-portion of the first waveguide, respectively, with the central being disposed between the first and second side-portions. A fourth dichroic mirror, a fifth dichroic mirror, and a sixth dichroic mirror, are embedded in a first side-portion, a central portion, and a second side-portion of the second waveguide, respectively, with the central portion being disposed between the first and second side-portions. The first, second, and third filters are disposed between the first side-portions, the central portions, and the second side-portions, respectively. The filters and dichroic mirrors are configured such that when only the first filter, only the second filter, and only the third filter is open, light, generated by the LSA, and incident on the first side-portion of the first waveguide, is filtered into the first, second, and third APCs, respectively, and is output at the second side-portion of the second waveguide.

According to some embodiments of the optical assembly, the CFA includes a first filter, a second filter, a third filter, and a fourth filter, which are individually openable and closeable by the control unit. Each filter is configured to transmit all light incident thereon when open, and block all light incident thereon when closed. The CFA further includes a first waveguide, a second waveguide, and a third waveguide, which are adjacently and successively disposed. The first waveguide has embedded, in a first side-portion thereof, a first beam splitting component, and, in a second side-portion thereof, a first mirror. The second waveguide has embedded, in a first side-portion thereof, a second beam splitting component, and, in a second side-portion thereof, a third beam splitting component. The third waveguide has embedded, in a first side-portion thereof, a second mirror, and, in a second side-portion thereof, a fourth beam splitting component. The first waveguide is configured to receive thereinto, at the first side-portion thereof, light generated by the LSA. The third waveguide is configured to output, from the second side-portion thereof, light received thereinto, Each of the beam splitting components is a dichroic mirror or a diffraction grating.

According to some embodiments of the optical assembly, the first filter is disposed between the first side-portion of the first waveguide and the first side-portion of the second waveguide, or is embedded within the first side-portion of the first waveguide. The second filter is disposed between the second side-portion of the first waveguide and the second side-portion of the second waveguide, or is embedded within the second side-portion of the first waveguide. The third filter is disposed between the first side-portion of the second waveguide and the first side-portion of the third waveguide, or is embedded within the first side-portion of the second waveguide. The fourth filter is disposed between the second side-portion of the second waveguide and the second side-portion of the third waveguide, or is embedded within the second side-portion of the first waveguide. The first dichroic mirror is configured to reflect only light in the first APC. The second dichroic mirror is configured to transmit only light in the third APC or reflect only light in the second APC. The third dichroic mirror is configured to transmit only light in the first APC or reflect only light in the second APC. The fourth dichroic mirror is configured reflect only light in the third APC. The positionings of the four filters, and actuation times thereof, are such that the first waveguide propagates there across only light in the first APC, the second waveguide propagates there across only light in the second APC, and the third waveguide propagates there across only light in the third APC.

According to some embodiments of the optical assembly, the three APCs include red, green, and blue (RGB).

According to some embodiments of the optical assembly, wherein the optical assembly includes the LCD array, the cells on the LCD array are arranged in a non-periodic pattern configured to suppress diffraction patterns (e.g. diffraction lobes) in light output by the CFA.

According to some embodiments of the optical assembly, the at least three intensity maps jointly constitute a color bitmap.

According to some embodiments of the optical assembly, the control unit is further configured to successively actuate light sources in the LSA according to a plurality of groups of intensity maps. Each group of intensity maps includes at least three intensity maps corresponding to the three APCs, such that the light output by the optical assembly corresponds to a sequence of video frames.

According to some embodiments of the optical assembly, the CFA is further configured to allow for controllable transmission therethrough of white light. The control unit is further configured to actuate light sources in the LSA according to an additional intensity maps, corresponding to white light.

According to some embodiments of the optical assembly, the optical assembly is coupled to a lightguide optical element (LOE). The LOE is configured to receive thereinto, light output by the optical assembly, propagate therethrough the light, and output the light together with ambient light incident on the LOE, such that a (virtual) image formed by the light from the optical assembly is overlaid on a (real) image formed by the ambient light.

According to an aspect of some embodiments, there is provided an augmented-reality (AR) near-eye display (NED) system including any one of the optical assemblies described above and the LOE described above.

According to an aspect of some embodiments, there is provided a method for overlaying a virtual (digital) image on a real image in an AR NED. The method includes, for each of three intensity maps corresponding to three APCs, respectively, stages of:

- Providing an AR NED as described above.
- Actuating broadband white light sources in an LSA of an optical assembly of the AR NED, according to the intensity map.
- Selectively filtering light produced by the LSA into the corresponding APC by passing the light through a CFA of the optical assembly;
- Directing light, filtered through the CFA, into a LOE of the AR NED.

According to an aspect of some embodiments, there is provided a method for overlaying a virtual image on a real image in an AR NED. The method includes, for each of three intensity maps corresponding to APCs, respectively, stages of:

Actuating broadband white light sources in a LSA of an optical assembly of an AR NED, according to the intensity map.

Selectively filtering light produced by the LSA into the corresponding APC by passing the light through a CFA of the optical assembly.

Directing light, filtered through the CFA, into a LOE of the AR NED.

The LOE is configured to output the filtered light together with ambient light incident on the LOE, such that an image formed by the filtered light is overlaid on an image formed by the ambient light.

According to some embodiments of the method, the LSA is a LED array.

According to some embodiments of the method, the LED array is an inorganic mLED array or an OLED array.

According to some embodiments of the method, the CFA includes an LCD array. Each cell in the LCD array corresponds to one of the three APCs, respectively. Cells corresponding to the same APC are jointly on and off switchable, such that (i) when switched on, each of the cells filters therethrough light in the corresponding APC, and (ii) when switched off, each of the cells blocks all light impinging thereon. The light generated by the LSA is polarized by a linear polarizer prior to being passed through the CFA.

According to some embodiments of the method, the CFA includes at least three color filters, individually on and off switchable. At least one of the color filters is configured to, when switched on, filter therethrough light in a respective APC from the three APCs, and, when switched off, block all light arriving thereat, and/or at least one of the color filters is configured to, when switched on, block light in a respective APC from the three APCs, and, when switched off, block all light arriving thereat. The at least three color filters are collectively switchable between three transmission modes, such that in each transmission mode light in a respective APC from the three APCs is filtered through the CFA.

According to some embodiments of the method, the at least three color filters include a first color filter, a second color filter, and a third color filter configured to filter therethrough light in the three APCs, respectively. The CFA further includes a first waveguide, configured to have transmitted thereinto light generated by the LSA, a second waveguide, and at least three dichroic mirrors. Each of the dichroic mirrors is configured to reflect or filter light in a respective APC from the three APCs. The three color filters are disposed between the waveguides. Each of the dichroic mirrors is embedded within one of the waveguides, such that (i) light generated by the LSA, and incident on a dichroic mirror, embedded in the first waveguide, is either directed thereby onto a respective one of the three color filters or onto an adjacent dichroic mirror in the first waveguide, and (ii) light filtered through the three color filters, and incident on a dichroic mirror, embedded in the second waveguide, is reflected inside the second waveguide.

According to some embodiments of the method, the at least three dichroic mirrors include six dichroic mirrors. A first dichroic mirror, a second dichroic mirror, and a third dichroic mirror, are embedded in a first side-portion, central portion, and second side-portion of the first waveguide, respectively. The central portion of the first waveguide is disposed between the first and second side-portions of the first waveguide. A fourth dichroic mirror, a fifth dichroic mirror, and a sixth dichroic mirror, are embedded in a first side-portion, central portion, and second side-portion of the second waveguide, respectively. The central portion of the second waveguide is disposed between the first and second side-portions of the second waveguide. The first, second, and third color filters are disposed between the first side-portions, the central portions, and the second side-portions, respectively. The first, second, and third color filters and dichroic mirrors are configured such that when only the first color filter, only the second color filter, and only the third color filter, is switched on, light, generated by the LSA, and incident on the first side-portion of the first waveguide, is filtered into the first, second, and third APCs, respectively, and is output at the second side-portion of the second waveguide.

According to some embodiments of the method, at least one of the at least three color filters includes a respective filter component and a respective shutter. The filter component is configured to transmit light only in the corresponding APC. Each shutter is configured to be controllably opened and closed at command, such that, when closed, the shutter prevents light from arriving at the respective filter component or blocks light transmitted through the respective filter component.

According to some embodiments of the method, the CFA further includes a first waveguide, a second waveguide, and a third waveguide, which are adjacently and successively disposed. The at least three color filters include four color filters including a first pair of color filters, disposed between the first waveguide and the second waveguide, and a second pair of color filters, disposed between the second waveguide and the third waveguide. The first waveguide has embedded, in a first side-portion thereof, a first beam splitting component, and, in a second side-portion thereof, a first mirror. The second waveguide has embedded, in a first side-portion thereof, a second beam splitting component, and, in a second side-portion thereof, a third beam splitting component. The third waveguide has embedded, in a first side-portion thereof, a second mirror, and, in a second side-portion thereof, a fourth beam splitting component. The first waveguide is configured to receive thereinto, at the first side-portion thereof, light generated by the LSA, and the third waveguide is configured to output, from the second side-portion thereof, light received thereinto.

According to some embodiments of the method, each of the beam splitting components is a dichroic mirror, a diffraction grating, or a dielectric beam splitter.

According to some embodiments of the method, a first of the four color filters is disposed between the first side-portion of the first waveguide and the first side-portion of the second waveguide, or embedded within the first side-portion of the first waveguide. A second of the four color filters is disposed between the second side-portion of the first waveguide and the second side-portion of the second waveguide, or embedded within the second side-portion of the first waveguide. A third of the four color filters is disposed between the first side-portion of the second waveguide and the first side-portion of the third waveguide, or embedded within the first side-portion of the second waveguide. A fourth of the four color filters is disposed between the second side-portion of the second waveguide and the second side-portion of the third waveguide, or embedded within the second side-portion of the first waveguide. APC filtering properties of each of the four color filters, positionings thereof, and actuation times, are such that the first waveguide propagates there across only light in the first APC, the second waveguide propagates there across only light in the second APC, and the third waveguide propagates there across only light in the third APC.

According to some embodiments of the method, (i) when switched on, the first color filter (i.e. the first of the four color filters) blocks only light in the first APC, (ii) when switched on, the second color filter (i.e. the second of the four color filters) filters therethrough only light in the first APC, (iii) when switched on, the third color filter (i.e. the third of the four color filters) filters therethrough only light in the second APC, and (iv) when switched on, the fourth color filter (i.e. the fourth of the four color filters) blocks only light in the second APC.

According to some embodiments of the method, the CFA includes a LCoS array. Each cell in the LCoS array includes sub-cells corresponding to each of the three APCs, respectively. The LCoS array is switchable between three reflection modes corresponding to the three APCs, such that in each reflection mode, each sub-cell corresponding to the APC reflects only light in the APC at a reflection level dictated by a respective one of three additional intensity maps, and the rest of the sub-cells are switched off. The light generated by the LSA is polarized by a linear polarizer prior to being passed through the CFA.

According to some embodiments of the method, each of the light sources in the LSA is configured to illuminate at least one cell from the cells in the LCoS array.

According to some embodiments of the method, the optical assembly is configured such that substantially every cell in the LCoS array is positioned to receive light substantially only from the respective light source in the LSA.

According to some embodiments of the method, the CFA further includes a first PBS and first collimating optics. The first PBS is configured to reflect polarized light, generated by the LSA or filtered through the polarization filter, towards the LCoS array. The first collimating optics is configured to collimate the reflected polarized light arriving thereat via the first PBS. The CFA is configured such that the collimated light is next indirectly output, having passed again through the first PBS, or directly output.

According to some embodiments of the method, the first collimating optics includes a collimating mirror arrangement. The CFA is configured such that the collimated light is indirectly output having passed again through the first PBS. The CFA further includes a quarter waveplate positioned between the first PBS and the collimating mirror arrangement, such that the on reentry to the first PBS, the polarization of the light has been rotated by 90°.

According to some embodiments of the method, wherein the light generated by the LSA is first passed through a second PBS and a second collimating optics, so as to be imaged on the LCoS array.

According to some embodiments of the method, the CFA includes a first filter, a second filter, and a third filter, which are individually openable and closeable by the controller. Each filter is configured to transmit all light incident thereon when open, and block all light incident thereon when closed. The CFA further includes a first waveguide, configured to have transmitted thereinto light generated by the LSA, a second waveguide, and at least three dichroic mirrors. Each of the dichroic mirrors is configured to reflect or filter light in a respective APC from the three APCs. The three filters (i.e. the first, second, and third filters) are disposed between the waveguides. Each of the dichroic mirrors is embedded within one of the waveguides, such that: (i) light generated by the LSA, and incident on a dichroic mirror, embedded in the first waveguide, is either directed thereby onto a respective one of the three filters or onto an adjacent dichroic mirror in the first waveguide, and (ii) light filtered through any of the three filters and incident on a dichroic mirror, embedded in the second waveguide, is reflected inside the second waveguide.

According to some embodiments of the method, the at least three dichroic mirrors include six dichroic mirrors. A first dichroic mirror, a second dichroic mirror, and a third dichroic mirror, are embedded in a first side-portion, a central portion, and a second side-portion of the first waveguide, respectively, with the central being disposed between the first and second side-portions. A fourth dichroic mirror, a fifth dichroic mirror, and a sixth dichroic mirror, are embedded in a first side-portion, a central portion, and a second side-portion of the second waveguide, respectively, with the central portion being disposed between the first and second side-portions. The first, second, and third filters are disposed between the first side-portions, the central portions, and the second side-portions, respectively. The filters and dichroic mirrors are configured such that when only the first filter, only the second filter, and only the third filter is open, light, generated by the LSA, and incident on the first side-portion of the first waveguide, is filtered into the first, second, and third APCs, respectively, and is output at the second side-portion of the second waveguide.

According to some embodiments of the method, the CFA includes a first filter, a second filter, a third filter, and a fourth filter, which are individually openable and closeable by the control unit. Each filter is configured to transmit all light incident thereon when open, and block all light incident thereon when closed. The CFA further includes a first waveguide, a second waveguide, and a third waveguide, which are adjacently and successively disposed. The first waveguide has embedded, in a first side-portion thereof, a first beam splitting component, and, in a second side-portion thereof, a first mirror.

The second waveguide has embedded, in a first side-portion thereof, a second beam splitting component, and, in a second side-portion thereof, a third beam splitting component. The third waveguide has embedded, in a first side-portion thereof, a second mirror, and, in a second side-portion thereof, a fourth beam splitting component. The first waveguide is configured to receive thereinto, at the first side-portion thereof, light generated by the LSA. The third waveguide is configured to output, from the second side-portion thereof, light received thereinto, Each of the beam splitting components is a dichroic mirror or a diffraction grating.

According to some embodiments of the method, the first filter is disposed between the first side-portion of the first waveguide and the first side-portion of the second waveguide, or is embedded within the first side-portion of the first waveguide. The second filter is disposed between the second side-portion of the first waveguide and the second side-portion of the second waveguide, or is embedded within the second side-portion of the first waveguide. The third filter is disposed between the first side-portion of the second waveguide and the first side-portion of the third waveguide, or is embedded within the first side-portion of the second waveguide. The fourth filter is disposed between the second side-portion of the second waveguide and the second side-portion of the third waveguide, or is embedded within the second side-portion of the first waveguide. The first dichroic mirror is configured to reflect only light in the first APC. The second dichroic mirror is configured to transmit only light in the third APC or reflect only light in the second APC. The third dichroic mirror is configured to transmit only light in the first APC or reflect only light in the second APC. The fourth dichroic mirror is configured reflect only light in the third APC. The positionings of the four filters, and actuation times thereof, are such that the first waveguide propagates there across only light in the first APC, the second waveguide propagates there across only light in the second APC, and the third waveguide propagates there across only light in the third APC.

According to some embodiments of the method, the three APCs include red, green, and blue (RGB).

According to some embodiments of the method, wherein the optical assembly includes the LCD array, the cells on the LCD array are arranged in a non-periodic pattern configured to suppress diffraction patterns in light output by the CFA.

According to some embodiments of the method, the at least three intensity maps jointly constitute a color bitmap.

According to some embodiments of the method, the light sources in the LSA are actuated according to a plurality of groups of intensity maps. Each group of intensity maps includes at least three intensity maps corresponding to the three APCs, such that images generated correspond to a sequence of video frames.

According to some embodiments of the method, the CFA is further configured to allow for controllable transmission therethrough of white light. The method further includes, following, in between, and/or after implementation of the stages thereof according to the three intensity maps:

Actuating the broadband white light sources in the LSA, according to an additional intensity map corresponding to white light.

Transmitting the white light through the CFA.

Directing the white light, transmitted through the CFA, into the LOE.

Certain embodiments of the present disclosure may include some, all, or none of the above advantages. One or more other technical advantages may be readily apparent to those skilled in the art from the figures, descriptions, and claims included herein. Moreover, while specific advantages have been enumerated above, various embodiments may include all, some, or none of the enumerated advantages.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure pertains. In case of conflict, the patent specification, including definitions, governs. As used herein, the indefinite articles “a” and “an” mean “at least one” or “one or more” unless the context clearly dictates otherwise.

Unless specifically stated otherwise, as apparent from the disclosure, it is appreciated that, according to some embodiments, terms such as “processing”, “computing”, “calculating”, “determining”, “estimating”, “assessing”, “gauging” or the like, may refer to the action and/or processes of a computer or computing system, or similar electronic computing device, that manipulate and/or transform data, represented as physical (e.g. electronic) quantities within the computing system’s registers and/or memories, into other data similarly represented as physical quantities within the computing system’s memories, registers or other such information storage, transmission or display devices.

Embodiments of the present disclosure may include apparatuses for performing the operations herein. The apparatuses may be specially constructed for the desired purposes or may include a general-purpose computer(s) selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a computer readable storage medium, such as, but not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, magnetic-optical disks, flash memories, read-only memories (ROMs), random access memories (RAMs), electrically programmable read-only memories (EPROMs), electrically erasable and programmable read only memories (EEPROMs), magnetic or optical cards, or any other type of media suitable for storing electronic instructions, and capable of being coupled to a computer system bus.

The processes and displays presented herein are not inherently related to any particular computer or other apparatus. Various general-purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct a more specialized apparatus to perform the desired method(s). The desired structure(s) for a variety of these systems appear from the description below. In addition, embodiments of the present disclosure are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the present disclosure as described herein.

Aspects of the disclosure may be described in the general context of computer-executable instructions, such as program modules, being executed by a computer. Generally, program modules include routines, programs, objects, components, data structures, and so forth, which perform particular tasks or implement particular abstract data types. Disclosed embodiments may also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules may be located in both local and remote computer storage media including memory storage devices.

BRIEF DESCRIPTION OF THE FIGURES

Some embodiments of the disclosure are described herein with reference to the accompanying figures. The description, together with the figures, makes apparent to a person having ordinary skill in the art how some embodiments may be practiced. The figures are for the purpose of illustrative description and no attempt is made to show structural details of an embodiment in more detail than is necessary for a fundamental understanding of the disclosure. For the sake of clarity, some objects depicted in the figures are not drawn to scale. Moreover, two different objects in the same figure may be drawn to different scales. In particular, the scale of some objects may be greatly exaggerated as compared to other objects in the same figure.

In the figures:

FIG. **1**A presents a block diagram of an optical assembly for generating a color image using white light as source, according to some embodiments;

FIG. **1**B schematically depicts a light source array of the optical assembly of FIG. **1**A, the light source array being configured to generate broadband white light according to some embodiments;

FIG. **1**C schematically depicts a lens and a handle of augmented reality glasses including an optical assembly corresponding to some embodiments of the optical assembly of FIG. **1**A;

FIG. **2**A schematically depicts an optical assembly for generating a color image using white light as source, the optical assembly including an LCD array and corresponding to specific embodiments of the optical assembly of FIG. **1**A;

FIG. **2**B schematically depicts the LCD array of FIG. **2**A, according to some embodiments;

FIG. **3**A schematically depicts an optical assembly for generating a color image using white light as source, which corresponds to specific embodiments of the optical assembly of FIG. 1A, the optical assembly includes a color filter arrangement including a plurality of color filters, according to some embodiments;

FIG. 3B schematically depicts the optical assembly of FIG. 3A, wherein the color filter arrangement is in a first transmission mode wherein only light in a first additive primary color is filtered through the color filter arrangement, according to some embodiments;

FIG. 3C schematically depicts the optical assembly of FIG. 3A, wherein the color filter arrangement is in a second transmission mode wherein only light in a second additive primary color is filtered through the color filter arrangement, according to some embodiments;

FIG. 3D schematically depicts the optical assembly of FIG. 3A, wherein the color filter arrangement is in a third transmission mode wherein only light in a third additive primary color is filtered through the color filter arrangement, according to some embodiments;

FIG. 4 schematically depicts an optical assembly for generating a color image using white light as source, which corresponds to specific embodiments of the optical assembly of FIG. 1A, the optical assembly includes a color filter arrangement including a plurality of color filters, according to some embodiments;

FIG. 5A schematically depicts an optical assembly for generating a color image using white light as source, the optical assembly including a LCoS array and corresponding to specific embodiments of the optical assembly of FIG. 1A;

FIG. 5B schematically depicts the LCoS array of FIG. 5A, according to some embodiments;

FIG. 6 schematically depicts an optical assembly for generating a color image using white light as source, the optical assembly including a LCoS array and corresponding to specific embodiments of the optical assembly of FIG. 1A; and

FIG. 7 presents a flowchart of a method for generating a color image using white light as source, according to some embodiments.

DETAILED DESCRIPTION

The principles, uses, and implementations of the teachings herein may be better understood with reference to the accompanying description and figures. Upon perusal of the description and figures present herein, one skilled in the art will be able to implement the teachings herein without undue effort or experimentation. In the figures, same reference numerals refer to same parts throughout.

In the description and claims of the application, the words "include" and "have", and forms thereof, are not limited to members in a list with which the words may be associated.

As used herein, the term "about" may be used to specify a value of a quantity or parameter (e.g. the length of an element) to within a continuous range of values in the neighborhood of (and including) a given (stated) value. According to some embodiments, "about" may specify the value of a parameter to be between 80% and 120% of the given value. For example, the statement "the length of the element is equal to about 1 m" is equivalent to the statement "the length of the element is between 0.8 m and 1.2 m". According to some embodiments, "about" may specify the value of a parameter to be between 90% and 110% of the given value. According to some embodiments, "about" may specify the value of a parameter to be between 95% and 105% of the given value.

As used herein, according to some embodiments, the terms "substantially" and "about" may be interchangeable.

Referring to the figures, in block diagrams and flowcharts, optional elements/components and stages may appear within boxes delineated by a dashed line.

As used herein, according to some embodiments, the term "color", with reference to light, is defined by an international standard, such as the CIE (International Commission on Illumination) RGB 1931 color space.

Systems

According to an aspect of some embodiments, there is provided an optical assembly for generating a color (e.g. a RGB image) using white light as a source. FIG. 1A schematically depicts such an optical assembly—an optical assembly **100**—according to some embodiments. Optical assembly **100** includes a light source array (LSA) **102**, a color filter arrangement (CFA) **104**, and a control unit **108**. Each of LSA **102** and CFA **104** is functionally associated with control unit **108** and configured to be commanded thereby, as indicated in FIG. 1A by dotted lines L_1 and L_2, and as elaborated on below. Optionally, according to some embodiments, optical assembly **100** may further include optics **110** configured to couple light generated by LSA **102** to CFA **104** and/or couple light output by CFA **104**, onto an output element, as elaborated on below. According to some embodiments, and as shown in FIG. 1A, the output element may be an (optical) waveguide, such as a lightguide optical element (LOE) **10** of an augmented reality (AR) near eye display (NED).

Referring also to FIG. 1B, FIG. 1B presents a schematic top view of LSA **102**, according to some embodiments. LSA **102** may include a plurality of broadband white light sources **112**. According to some embodiments, light sources **112** in LSA **102** may be individually addressable by control unit **108**. According to some such embodiments, control unit **108** may be configured to control switching on and off of each of light sources **112** and intensities of each of light sources **112**. More specifically, LSA **102** may be configured to generate illumination patterns based on intensity values—per each of light sources **112**, respectively—received from control unit **108**.

According to some embodiments, LSA **102** is a light-emitting diode (LED) array. That is, each of light sources **112** is a LED (configured to emit broadband white light). According to some such embodiments, LSA **102** is an inorganic micro-LED array (mLED) array or an organic LED (OLED) array. That is, each of the LEDs is an inorganic mLED or an OLED.

CFA **104** may be switchable by control unit **108** between three transmission modes respectively corresponding to the three additive primary colors (APCs)—i.e. red, green, and blue. In each of the transmission modes, CFA **104** may be configured to filter therethrough light at a range of wavelengths corresponding to a respective APC. More specifically, CFA **104** may be switchable at least between:

- a first transmission mode, wherein CFA **104** blocks all visible light, except light in a first APC;
- a second transmission mode, wherein CFA **104** blocks all visible light, except light in a second APC; and
- a third transmission mode, wherein CFA **104** blocks all visible light, except light in a third APC.

According to some embodiments, CFA **104** may be further switchable to a fourth transmission mode, corresponding to white light. Accordingly, in the fourth transmission mode, CFA **104** may be configured to transmit all visible light.

According to some embodiments, given image data in the form of three intensity maps corresponding to each of the three APCs, respectively—that is, given a color bitmap (specifying RGB intensities)—control unit **108** may be configured to successively send to LSA **102** each of the intensity maps. Each of the intensity maps includes the intensity values, associated with a respective APC, which are assigned to the pixels by the color bitmap. The intensity maps thus correspond to a two-dimensional (spatial) intensity distribution in each of the APCs, respectively. Each of the intensity maps dictates to each of light sources **112**, a respective intensity value. As described in detail below, by sufficiently rapidly actuating light sources **112**, according to each of the intensity maps, the generated illumination patterns—after filtering by CFA **104** (and, optionally, passage through an output element, such as LOE **10**)— are effectively combined, so as to be perceivable by eye as a single color image (which the color bitmap encodes).

According to some embodiments, LOE **10** may be a slab waveguide. As a non-limiting example, when the AR NED is a pair of AR glasses, the LOE may constitute, or form part of, a lens of the glasses.

According to some embodiments, LOE **10** may include two or more sets of parallel partially-reflective mirrors. Different sets of partially reflective mirrors may or may not be parallel to one another. According to some embodiments, LOE **10** be a diffractive waveguide. That is, a waveguide with embedded or partially embedded diffraction gratings configured to for inputting light into the waveguide and outputting light therefrom.

Control unit **108** includes control circuitry configured to synchronize (i.e. coordinate) operations of LSA **102** and CFA **104**, such that when LSA **102** produces an illumination pattern according to one of the three APCs, CFA **104** is simultaneously in a transmission mode configured to filter therethrough only light at the same APC (i.e. the APC according to which the illumination pattern is being produced). Thus, (i) when LSA **102** produces an illumination pattern according to a first intensity map, corresponding to a first APC, CFA **104** is in the first transmission mode, (ii) when LSA **102** produces an illumination pattern according to a second intensity map, corresponding to a second APC, CFA **104** is in the second transmission mode, and (iii) when LSA **102** produces an illumination pattern according to a third intensity map, corresponding to a third APC, CFA **104** is in the third transmission mode.

In operation, light generated by LSA **102**, indicated by dashed arrows **101**, is filtered by CFA **104**, wherefrom the filtered light, indicated by arrows **103**, propagates towards LOE **10** (in embodiments wherein the output element is a LOE) and enters thereinto. LOE **10** may be transparent, so that the environment is visible to a subject wearing an AR NED including optical assembly **100** and LOE **10**. More precisely, LOE **10** is configured to output the filtered light and ambient light (i.e. external light from the environment; indicated by dashed arrows **111**) onto an eye(s) **5** of the subject (wearing an AR NED), such that the filtered light forms a virtual image, which is overlaid on a real image formed by the ambient light.

According to some embodiments, wherein optical assembly **100** includes optics **110**, optics **110** may be configured to guide the light, generated by LSA **102**, onto CFA **104**. According to some embodiments, optics **110** may be configured to collimate the light, generated by LSA **102**. According to some such embodiments, optics **110** may include one or more collimating lenses, which may be positioned between LSA **102** and CFA **104**, as described below.

According to some embodiments, control unit **108** includes one or more processing components and volatile and/or non-volatile memory components. Control unit **108** may be configured to receive a stream of color bitmaps, which may be stored in the volatile memory (i.e. random access memory (RAM)). The three intensity maps, making up each color bitmap, may be successively sent to LSA **502**. According to some embodiments, control unit **108** may be configured to receive the color bitmaps by wireless communication, in which case control unit **108** may include a Wi-Fi antenna and/or a Bluetooth antenna. According to some embodiments, control unit **108** may be communicatively associated with, and configured to be controlled by, a processor of an AR NED which includes optical assembly **100**.

According to some embodiments, the first APC may be red, green, or blue, the second APC may be red, green, or blue, contingent on being different from the first APC, and the third APC may be red, green, or blue, contingent on being different from both the first APC and the second APC. As non-limiting examples, the first APC may be red, the second APC may be green, and the third APC may be blue, or the first APC may be green, the second APC may be blue, and the third APC may be red.

FIG. **1**C schematically depicts an AR NED **2** in the form of glasses, according to some embodiments. AR NED **2** includes an optical assembly **100'** and a LOE **10'**, which correspond to specific embodiments of optical assembly **100** and LOE **10**, respectively. Further shown are a handle **4** and a lens **6** of AR NED **2**. Lens **6** may be mounted on handle **4**. According to some embodiments, LOE **10'** is constituted by lens **6**. Alternatively, according to some embodiments, LOE **10'** is included in lens **6**. Optical assembly **100'** is positioned behind LOE **10'** adjacently to a first side-portion thereof (not numbered). According to some embodiments, optical assembly **100'** may be embedded in, or, as shown in FIG. **1**C, partially embedded in, handle **4**.

FIG. **2**A schematically depicts an optical assembly **200**, according to some embodiments. Optical assembly **200** corresponds to specific embodiments of optical assembly **100**, wherein the CFA includes a color selective switch based on a liquid crystal display (LCD) array. Optical assembly **200** includes an LSA **202**, a CFA **204** including an LCD array **220**, and a control unit **208**. Each of LSA **202**, CFA **204**, and control unit **208** corresponds to specific embodiments of LSA **102**, CFA **104**, and control unit **108**, respectively. According to some embodiments, and as depicted in FIG. **2**A, optical assembly **200** further includes optics **210**, which corresponds to specific embodiments of optics **110**.

Referring also to FIG. **2**B, FIG. **2**B depicts LCD array **220**, according to some embodiments. LCD array **220** includes a plurality of cells **224**, each of which corresponds to one of the three APCs. Cells **224** include first cells **224*a***, second cells **224*b***, and third cells **224*c*** corresponding to the first APC, second APC, and third APC, respectively. Cells corresponding to the same color are jointly on and off switchable by control unit **208**. When switched off, a cell blocks all light impinging thereon. When switched on, a cell filters therethrough only light at the APC corresponding thereto.

More specifically, according to some embodiments, LCD array **220** is switchable by control unit **208** between three transmission modes:

In a first transmission mode, first cells **224*a*** are (jointly) switched on and second cells **224*b*** and third cells **224*c*** are (jointly) switched off, so that LCD array **220** blocks all light except light in the first APC.

In a second transmission mode, second cells **224***b* are (jointly) switched on and third cells **224***c* and first cells **224***a* are (jointly) switched off, so that LCD array **220** blocks all light except light in the second APC.

In a third transmission mode, third cells **224***c* are (jointly) switched on and second cells **224***b* and third cells **224***c* are (jointly) switched off, so that LCD array **220** blocks all light except light in the third APC.

It is noted that in state-of-the-art LCD arrays, each cell is individually addressable in the sense that the transmission level of the cell (i.e. the percentage of light impinging on the cell, which is filtered therethrough) is controllable. This is achieved by means of a thin film transistor (TFT), which is mounted behind the cell and configured to apply a voltage of a controllable magnitude across the cell. However, the smaller the cell, the greater the dimensions of the TFT as compared to the cell, and, consequently, the greater the percentage of impinging light that is blocked, even when the transmission level is set to maximum. Hence, there is trade-off between the dimensions of the cells and the maximum transmission and the resulting quality of the images: the smaller the cells, the lesser the maximum brightness and the contrast. In particular, cells that are too large may cause local variations in the intensity of the light input into the LOE, which in turn may lead to local variations in the intensity of the (virtual) image projected onto the retina of a user (i.e. wearing the AR NED). However, if the pixels are sufficiently small as compared to the size of the (human eye) pupil, such variations would not be observed by the user.

Optical assembly **200** overcomes this limitation by forgoing the option of individually addressing of cells, so that comparatively simpler and less space consuming electronics may be used. More specifically, since all cells of the same type (i.e. corresponding to the same APC) operate together in a binary mode (i.e. are all fully transmitting or fully blocking), the anodes of all cells of the same type could be jointly short-circuited, and, similarly, the cathodes of the cells could be jointly short-circuited, so that the same voltage is applied across each of the cells. Hence, only three electrical switches are required: one per each type of cells. At the level of the individual cell, the connections to the respective anode and cathode may occupy a few square micrometers (e.g. about 10 μm^2 or even about 5 μm^2), with the result that significantly less (e.g. less than 10%) of the light impinging on a cell is blocked even when the cells are small (e.g. measuring 20 $\mu m \times 20$ μm in area). Since the effective pupil of the system (i.e. the human pupil) has a diameter of about 4 mm (so that about 30,000 cells may be imaged there onto), as explained above, local variations of intensity will not be perceivable. The produced images are advantageously thus both bright and uniform.

Cells **224** may be arranged in any pattern known in the art of LCDs. According to some embodiments, and as depicted in FIG. **2**B, cells **224** may be arranged in a non-periodic pattern, so as to eliminate occurrence of diffraction lobes or at the very least suppress diffraction lobes.

According to some embodiments, and as depicted in FIG. **2**A, optics **210** may include a collimating lens **228**. Collimating lens **228** may be configured to collimate light generated by LSA **202** onto LCD array **220**.

According to some embodiments, LSA **202** may be a LED array, such as an inorganic mLED array or an OLED array configured generate broadband white light.

According to some embodiments, and as depicted in FIG. **2**A, optics **210** may include a polarizer **234**. Polarizer **234** may be positioned between LSA **202** and CFA **204** (e.g. between collimating lens **228** and LCD array **220**), so as to ensure that light—originating in LSA **202** and impinging on LCD array **220**—is polarized. According to some embodiments, polarizer **234** is a linear polarizer.

According to some alternative embodiments, instead of LCD array **220**, a Lyot filter or a rotatable wheel with color filters may be employed. More generally, in embodiments wherein each pixel in the virtual image arises from a plane wave having a respective angular orientation (or, equivalently, in embodiments wherein the light produced by the LSA is collimated such as to appear as arriving from the eye from infinity), a global chromatic shutter may be employed, such the global chromatic shutters mentioned above and similar thereto.

Also shown in FIG. **2**A are trajectories of light rays (indicated by dashed arrows **201**, not all of which are numbered) from LSA **202**, via collimating lens **228** and polarizer **234**, to LCD array **220**, and from LCD array **220** to LOE **20**. According to some embodiments, light filtered through LCD array **220** may enter LOE **20** on a first end-portion **26** of LOE **20**, and be reflected—for example, by a mirror(s) **22** embedded in first end-portion **26**—such as to be propagated to a second end-portion **28** of LOE **20**, which is opposite to first end-portion **26**. Second end-portion **28** may include one or beam splitting components **24** (not all of which are numbered) configured to output the light propagated from first end-portion **28** together with ambient light (indicated by dashed arrows **203**; not all of which are numbered). Outputted light rays are indicated by dashed arrows **205** (not all of which are numbered).

FIG. **3**A schematically depicts an optical assembly **300**, according to some embodiments. Optical assembly **300** corresponds to specific embodiments of optical assembly **100**, wherein the CFA includes a plurality of color filters and waveguides. Optical assembly **300** includes an LSA **302**, a CFA **304** including a plurality of color filters **330** and a plurality of waveguides **340**, and a control unit **308**. Each of LSA **302**, CFA **304**, and control unit **308** corresponds to specific embodiments of LSA **102**, CFA **104**, and control unit **108**, respectively. According to some embodiments, and as depicted in FIG. **3**A, optical assembly **300** further includes optics **310**, which corresponds to specific embodiments of optics **110**.

According to some embodiments, LSA **302** may be a LED array, such as, for example, an inorganic mLED array or an OLED array.

According to some embodiments, and as depicted in FIG. **3**A, color filters **330** include a first color filter **330***a*, a second color filter **330***b*, a third color filter **330***c*, and a fourth color filter **330***d*. According to some embodiments, first color filter **330***a*, when switched on, may be configured to block light in the first APC. Second color filter **330***b*, when switched on, may be configured to filter therethrough light in the first APC. Third color filter **330***c*, when switched on, may be configured to block light in the second APC. Fourth color filter **330***d*, when switched on, may be configured to filter therethrough light in the second APC. Each of color filters **330**, when switched off, is configured to block all light or at least all visible light.

According to some embodiments, and as depicted in FIG. **3**A, waveguides **340** include a three successively and adjacently disposed waveguides: a first waveguide **340***a*, a second waveguide **340***b*, and a third waveguide **340***c*. First waveguide **340***a* includes a first side-portion **342***a***1** and a second side-portion **342***a***2** positioned oppositely to first side-portion **342***a***1**. Similarly, second waveguide **340***b* includes a first side-portion **342***b***1** and a second side-portion **342***b***2** positioned oppositely to first side-portion **342***b***1**.

Finally, third waveguide **340***c* includes a first side-portion **342***c***1** and a second side-portion **342***c***2** positioned oppositely to first side-portion **342***c***1**. First waveguide **340***a*, second waveguide **340***b*, and third waveguide **340***c* are disposed in parallel to one another with second waveguide **340***b* being positioned between first waveguide **340***a* and third waveguide **340***c*.

According to some embodiments, each of waveguides **340** may be a slab waveguide.

According to some embodiments, and as depicted in FIG. 3A, each of waveguides **340** has embedded therein one or two beam splitting components, respectively. A first beam splitting component **344***a* is embedded in first side-portion **342***a***1** of first waveguide **340***a*. A second beam splitting component **344***b***1** and a third beam splitting component **344***b***2** are embedded in first side-portion **342***b***1** and second side-portion **342***b***2**, respectively, of second waveguide **340***b*. A fourth beam splitting component **344***c* is embedded in second side-portion **342***c***2** of second waveguide **340***b*. According to some embodiments, first waveguide **340***a* may have embedded in second side-portion **342***a***2** a first mirror **346***a*, and third waveguide **340***c* may have embedded in first side-portion **342***c***1** a second mirror **346***c*.

According to some embodiments, one or more of beam splitting components **344** may be a dichroic mirror, as described in detail below. According to some embodiments, diffraction gratings may be employed instead of dichroic mirrors. According to some embodiments, waveguides **340** may be diffractive waveguides. According to some embodiments, one or more of beam splitting components **344** may be dielectric beam splitters.

According to some embodiments, first color filter **330***a* and second color filter **330***b* may be disposed between first waveguide **340***a* and second waveguide **340***b*, and third color filter **330***c* and fourth color filter **330***d* may be disposed between second waveguide **340***b* and third waveguide **340***c*: First color filter **330***a* may be disposed between first side-portion **342***a***1** and first side-portion **342***b***1**. Second color filter **330***b* may be disposed between second side-portion **342***a***2** and second side-portion **342***b***2**. Third color filter **330***c* may be disposed between first side-portion **342***b***1** and first side-portion **342***c***1**. Fourth color filter **330***d* may be disposed between second side-portion **342***b***2** and second side-portion **342***c***2**.

According to some embodiments, and as depicted in FIG. 3A, first waveguide **340***a* may be positioned such that light generated by LSA **302** enters CFA **304** via first side-portion **342***a***1**. Waveguides **340**, color filters **330**, beam splitting components **344**, and mirrors **346** relative positions and orientations may be such that light, selectively filtered through CFA **304**, exits CFA **304** via second side-portion **342***c***2** of third waveguide **340***c*, as elaborated on below. In particular, color filters **330**, beam splitting components **344**, and mirrors **346** relative positions and orientations may be such that in order to transition from first waveguide **340***a* to second waveguide **340***b*, light must necessarily pass through one of first color filter **330***a* and second color filter **330***b*, and in order to transition from second waveguide **340***b* to third waveguide **340***c*, light must necessarily pass through one of third color filter **330***c* and fourth color filter **330***d*.

According to some embodiments, both above and below first beam splitting component **344***a* and below first mirror **346***a*, first waveguide **340***a* may be coated with an anti-reflective coating. Similarly, both above and below second beam splitting component **344***b***1** and third beam splitting component **344***b***2**, second waveguide **340***b* may be coated with an anti-reflective coating. Finally, above second mirror **346***c* and above and below fourth beam splitting component **344***c*, third waveguide **340***c* may be coated with an anti-reflective coating. The anti-reflective coating may minimize undesirable reflections off the surfaces of waveguides **340**, thereby reducing loss of intensity.

According to some embodiments, CFA **304** is switchable by control unit **308** between three transmission modes:

In a first transmission mode, CFA **304** filters therethrough light in the first APC with first color filter **330***a* switched off and second color filter **330***b* and fourth color filter **330***d* switched on. (Third color filter **330***c* may be switched on or off.) As shown in FIG. 3B, the filtered light propagates along first waveguide **340***a* from first side-portion **342***a***1** to second side-portion **342***a***2**, and exits CFA **304** via second side-portion **342***c***2** of third waveguide **340***c* after having passed through second side-portion **342***b***2** of second waveguide **340***b*.

In a second transmission mode, CFA **304** filters therethrough light in the second APC with first color filter **330***a* switched on, second color filter **330***b* and third color filter **330***c* switched off, and fourth color filter **330***d* switched on. As shown in FIG. 3C, the filtered light enters second waveguide **340***b* via first side-portion **342***b***1**, after having passed through first side-portion **342***a***1** of first waveguide **340***a*. The filtered light propagates along second waveguide **340***b* from first side-portion **342***b***1** to second side-portion **342***b***2**, and exits CFA **304** via second side-portion **342***c***2** of third waveguide **340***c*.

In a third transmission mode, CFA **304** filters therethrough light in the third APC with first color filter **330***a* switched on, second color filter **330***b* switched off, third color filter **330***c* switched on, and fourth color filter **330***d* switched off. As shown in FIG. 3D, the filtered light enters third waveguide **340***c* via first side-portion **342***c***1**, after having passed through first side-portion **342***a***1** of first waveguide **340***a* and second side-portion **342***b***2** of second waveguide **340***b*. The filtered light propagates along third waveguide **340***c* from first side-portion **342***c***1** to second side-portion **342***c***2**, wherefrom the filtered light exits CFA **304**.

FIG. 3B schematically depicts filtering of light generated by LSA **302** when CFA **304** is in the first transmission mode, according to some embodiments. Light (indicated by a dashed arrow **301**), incident on first side-portion **342***a***1**, is partially reflected and partially transmitted by first beam splitting component **344***a*, with the reflected light (indicated by dashed arrows **303**) propagating along first waveguide **340***a* towards first mirror **346***a*, and the transmitted light (not shown), on exiting first waveguide **340***a*, being blocked by first color filter **330***a* (which is switched off in the first transmission mode). The propagated light is next reflected by first mirror **346***a*, exits first waveguide **340***a* via second side-portion **342***a***2**, and is filtered into the first APC by second filter **330***b* (as indicated by dashed arrow **305**). Next, the filtered light enters second waveguide **340***b* via second side-portion **342***b***2**. In second side-portion **342***b***2**, the entered light is partially transmitted by third beam splitting component **344***b***2**. The light transmitted by third beam splitting component **344***b***2** exits second waveguide **340***b* (via second side-portion **342***b***2**) towards fourth color filter **330***d*, is filtered therethrough (as indicated by a dashed arrow **307**), and enters third waveguide **340***c* (via second side-portion **342***c***2**). In second side-portion **342***c***2**, the entered light is partially transmitted by fourth beam splitting component **344***c*. The transmitted light exits third waveguide **340***c* (as indicated by a dashed arrow **309**).

FIG. **3**C schematically depicts filtering of light generated by LSA **302** when CFA **304** is in the third transmission mode, according to some embodiments. Light (indicated by dashed arrow **301**), incident on first side-portion **342***a***1**, is partially transmitted by first beam splitting component **344***a*, with the transmitted light being filtered through first color filter **330***a* (as indicated by a dashed arrow **303'**) into the second and third APCs. The light (not shown), reflected by first beam splitting component **344***a*, propagates along first waveguide **340***a* towards first mirror **346***a*, is reflected thereby, and on exiting from first waveguide **340***a*, via second side-portion **342***a***2**, is blocked by second color filter **330***b* (which is switched off in the second transmission mode). The filtered light enters second waveguide **340***b* (via first side-portion **342***b***1**), is partially reflected by second beam splitting component **344***b***1**, and propagates along second waveguide **340***b* (as indicated by dashed arrows **305'**). The light (not shown) transmitted by second beam splitting component **344***b***1**, on exiting second waveguide **340***b*, is blocked by third color filter **330***c* (which is switched off in the second transmission mode). The light propagated along second waveguide **340***b* is next partially transmitted by third beam splitting component **344***b***2**, exits second waveguide **340***b* (via second side-portion **342***b***2**), and is filtered into the second APC by fourth color filter **330***d* (as indicated by a dashed arrow **307'**). The filtered light enters third waveguide **340***c* (via second side-portion **342***c***2**). In second side-portion **342***c***2**, the entered light is partially transmitted by fourth beam splitting component **344***c*. The transmitted light exits third waveguide **340***c* (as indicated by a dashed arrow **309'**).

FIG. **3**D schematically depicts filtering of light generated by LSA **302** when CFA **304** is in the third transmission mode, according to some embodiments. Light (indicated by dashed arrow **301**), incident on first side-portion **342***a***1**, is partially transmitted by first beam splitting component **344***a*, with the transmitted light being filtered through first color filter **330***a* (as indicated by dashed arrow **303'**) into the second and third APCs. The light (not shown), reflected by first beam splitting component **344***a*, propagates along first waveguide **340***a* towards first mirror **346***a*, is reflected thereby, and on exiting from first waveguide **340***a*, via second side-portion **342***a***2**, is blocked by second color filter **330***b* (which is switched off in the third transmission mode). The filtered light enters second waveguide **340***b* (via first side-portion **342***b***1**), is partially transmitted by second beam splitting component reflected by second beam splitting component **344***b***1**, propagates along second waveguide **340***b*, is partially reflected by third beam splitting component **344***b***2**, and, on exiting second side-portion **342***b***2**, is blocked by fourth color filter **330***d* (which is switched off in the third transmission mode). The light exiting first-side portion **342***b***1** (i.e. the light transmitted by second beam splitting component **344***b***1**), is filtered by third color filter **330***c* into the third APC (as indicated by a dashed arrow **305"**), and next enters third waveguide **340***c* (via first side-portion **342***c***1**). In first side-portion **342***c***1**, the entered light is reflected by second mirror **346***c*. The reflected light propagates along third waveguide **340***c* (as indicated by dashed arrows **307"**), is partially reflected by fourth beam splitting component **344***c*, and exits third waveguide **340***c* via second side-portion **342***c***2** (as indicated by a dashed arrow **309"**).

According to some embodiments, first beam splitting component **344***a* may be a dichroic mirror configured to transmit light in each of the second and third APCs and to reflect light in the first APC. Second beam splitting component **344***b***1** may be a dichroic mirror configured to transmit light in the third APC and to reflect light in the second APC. Third beam splitting component **344***b***2** may be a dichroic mirror configured to transmit light in the first APC and to reflect light in the second APC. Fourth beam splitting component **344***c* may be a dichroic mirror configured to transmit light in the first and second APCs and to reflect light in the third APC. According to some such embodiments (i.e. embodiments wherein beam splitting components **344** are dichroic mirrors, as described above, or diffraction gratings having the same APC filtering properties) instead of color filters **330**, filters without color filtering capabilities (e.g. shutters) may be employed.

According to some embodiments, each of color filters **330** includes a respective filter component (a static filter; not shown) and a respective shutter. According to some such embodiments, each of the filter components of first color filter **330***a* and fourth color filter **330***d* may be configured to block light in the respective APC. Each of the filter components of second color filter **330***b* and third color filter **330***c* may be configured to filter therethrough light in the respective APC. Each shutter is configured to be controllably opened and closed at command from control unit **308**, such that, when closed, the shutter prevents light from arriving at the respective filter component or blocks light transmitted through the respective filter component. According to some embodiments, the shutters may be mechanically actuated. Alternatively, according to some embodiments, each of the shutters may be an LCD panel, in which case, optics **310** may additionally include a linear polarizer (not shown) positioned between LSA **302** and CFA **304**.

According to some embodiments, dichroic mirrors **344** need not be perfect in the sense of not acting as a perfect band pass filter. For example, according to some such embodiments, outside the chromatic band(s), transmitted/reflected therethrough, dichroic mirrors **344** may transmit/reflect light at an attenuated intensity rather than fully blocking the light. As used herein, according to some embodiments, the term “dichroic mirror” may be used in an expansive manner to cover also imperfect dichroic mirrors, as described above.

According to some embodiments, optics **310** includes a collimating lens **328** positioned between LSA **302** and CFA **304**.

FIG. **4** schematically depicts an optical assembly **400**, according to some embodiments. Optical assembly **400** corresponds to specific embodiments of optical assembly **100**, wherein the CFA includes a plurality of color filters and waveguides. Optical assembly **400** includes an LSA **402**, a CFA **404** including a plurality of color filters **430** and a plurality of waveguides **440**, and a control unit **408**. Each of LSA **402**, CFA **404**, and control unit **408** corresponds to specific embodiments of LSA **102**, CFA **104**, and control unit **108**, respectively. According to some embodiments, and as depicted in FIG. **4**, optical assembly **400** further includes optics **410**, which corresponds to specific embodiments of optics **410**.

According to some embodiments, LSA **402** may be a LED array, such as an inorganic mLED array or an OLED array.

According to some embodiments, and as depicted in FIG. **4**, color filters **430** include a first color filter **430***a*, a second color filter **430***b*, and a third color filter **430***c*. First color filter **430***a*, when switched on, is configured to block all visible light except light in the first APC. Second color filter **430***b*, when switched on, is configured to block all visible light except light in the second APC. Third color filter **430***c*, when switched on, is configured to block all visible light except light in the third APC. Each of color filters **430**, when switched off, is configured to block all visible light.

According to some embodiments, and as depicted in FIG. **4**, waveguides **440** include a first waveguide **440***a* and a second waveguide **440***b*. First waveguide **440***a* includes a first side-portion **442***a***1**, a central portion **442***a***2**, and a second side-portion **442***a***3**. Central portion **442***a***2** extends from first side portion **442***a***1** to second side-portion **442***a***3**. Similarly, second waveguide **440***b* includes a first side-portion **442***b***1**, a central portion **442***b***2**, and a second side-portion **442***b***3**. Central portion **442***b***2** extends from first side-portion **442***b***1** to second side-portion **442***b***3**. First waveguide **440***a* and second waveguide **440***b* are disposed in parallel to one another.

According to some embodiments, each of waveguides **440** may be a slab waveguide.

According to some embodiments, and as depicted in FIG. **4**, each of first waveguide **440***a* and second waveguide **440***b* has embedded therein a plurality of dichroic mirrors **444***a* and **444***b*, respectively: A first dichroic mirror **444***a***1** is embedded in first side-portion **442***a***1** of first waveguide **440***a*. A second dichroic mirror **444***a***2** is embedded in central portion **442***a***2** of first waveguide **440***a*. A third dichroic mirror **444***a***3** is embedded in second side-portion **442***a***3** of first waveguide **440***a*. (So that third dichroic mirror **444***a***3** is positioned adjacently to second dichroic mirror **444***a***2**, which, in turn, is positioned adjacently to first dichroic mirror **444***a***1**.) A fourth dichroic mirror **444***b***1** is embedded in first side-portion **442***b***1** of second waveguide **440***b*. A fifth dichroic mirror **444***b***2** is embedded in central portion **442***b***2** of second waveguide **440***b*. A sixth dichroic mirror **444***b***3** is embedded in second side-portion **442***b***3** of second waveguide **440***b*. (So that sixth dichroic mirror **444***b***3** is positioned adjacently to fifth dichroic mirror **444***b***2**, which, in turn, is positioned adjacently to fourth dichroic mirror **444***b***1**.)

Color filters **430** are disposed between first waveguide **440***a* and second waveguide **440***b*. First color filter **430***a* may be disposed between first side-portion **442***a***1** of first waveguide **440***a* and first side-portion **442***b***1** of second waveguide **440***b*. Second color filter **430***b* may be disposed between central portion **442***a***2** of first waveguide **440***a* and central portion **442***b***2** of second waveguide **440***b*. Third color filter **430***c* may be disposed between second side-portion **442***a***3** of first waveguide **440***a* and second side-portion **442***b***3** of second waveguide **440***b*.

According to some embodiments, and as depicted in FIG. **4**, first waveguide **440***a* may be positioned such that light generated by LSA **402** enters CFA **404** via first side-portion **442***a***1**. Waveguides **440** and dichroic mirrors **444** (i.e. dichroic mirrors **444***a* and **444***b*) relative positions and orientations may be such that light, selectively filtered through CFA **404**, exits CFA **404** via second side-portion **442***b***3** of second waveguide **440***b*, as elaborated on below. In particular, color filters **430** and dichroic mirrors **444** relative positions and orientations may be such that in order to transition from first waveguide **440***a* to second waveguide **440***b*, light must necessarily pass through one of color filters **430**.

According to some embodiments, CFA **404** is switchable by control unit **408** between three transmission modes:

- In a first transmission mode, CFA **404** filters therethrough light in the first APC. First color filter **430***a* is switched on and second color filter **430***b* and third color filter **430***c* are switched off.
- In a second transmission mode, CFA **404** filters therethrough light in the second APC. Second color filter **430***b* is switched on and third color filter **430***c* and first color filter **430***a* are switched off.
- In a third transmission mode, CFA **404** filters therethrough light in the third APC. Third color filter **430***c* is switched on and first color filter **430***a* and second color filter **430***b* are switched off.

According to some embodiments, first dichroic mirror **444***a***1** may be configured to transmit only light in the first APC, second dichroic mirror **444***a***2** may be configured to reflect only light in the second APC or transmit only light in the third APC, third dichroic mirror **444***a***3** may be configured to reflect only light in the third APC. According to some embodiments, fourth dichroic mirror **444***b***1** may be configured to reflect only light in the first APC, fifth dichroic mirror **444***b***2** may be configured to reflect only light in the second APC, and sixth dichroic mirror **444***b***3** may be configured to reflect only light in the third APC.

Accordingly, in such embodiments, when only first color filter **430***a* is switched on, light incident on first side-portion **442***a***1** (*a*) is filtered by first dichroic mirror **444***a***1** into the first APC, (b) exits first waveguide **440***a* via first side-portion **442***a***1**, (c) is transmitted through first color filter **430***a*, (d) enters second waveguide **440***b* via first side-portion **442***b***1**, (e) is reflected by fourth dichroic mirror **444***b***1** onto fifth dichroic mirror **444***b***2**, (f) is transmitted through fifth dichroic mirror **444***b***2**, and (g) is output after transmission through sixth dichroic mirror **444***b***3**. When only second color filter **430***b* is switched on, light incident on first side-portion **442***a***1** (*a*) is reflected into the second and third APCs by first dichroic mirror **444***a***1** in the direction of second dichroic mirror **444***a***2**, (b) is reflected by second dichroic mirror **444***a***2** into the second APC, (c') exits first waveguide **440***a* via central portion **442***a***2**, (d) is transmitted through second color filter **430***b*, (e') enters second waveguide **440***b* via central portion **442***b***2**, (f) is reflected by fifth dichroic mirror **444***b***2** onto sixth dichroic mirror **444***b***3**, and (g') is output after transmission through sixth dichroic mirror **444***b***3**. When only third color filter **430***c* is switched on, light incident on first side-portion **442***a***1**, (a') is reflected into the second and third APCs by first dichroic mirror **444***a***1** in the direction of second dichroic mirror **444***a***2**, (b') is filtered into the third APC by second dichroic mirror **444***a***2**, (c') is reflected by third dichroic mirror **444***a***3**, (d') exits first waveguide **440***a* via second side-portion **442***a***3**, (e) is transmitted through third color filter **430***c*, (f) enters second waveguide **440***b* via second side-portion **442***b***3**, and (g') is output after reflection by sixth dichroic mirror **444***b***3**.

According to some embodiments, dichroic mirrors **444** need not be perfect in the sense of not acting as a perfect band pass filter. For example, according to some such embodiments, outside the chromatic band(s), filtered/reflected therethrough, dichroic mirrors **444** may pass/reflect light at an attenuated intensity rather than fully blocking the light.

According to some alternative embodiments, instead of third dichroic mirror **444***a***3**, first waveguide **440***a* may have embedded a standard mirror (i.e. reflecting all light), and/or instead of fourth dichroic mirror **444***b***1**, second waveguide **440***b* may have embedded therein a standard mirror.

According to some alternative embodiments, instead of one or more of first dichroic mirror **444***a***1**, second dichroic mirror **444***a***2**, fifth dichroic mirror **444***b***2**, and sixth dichroic mirror **444***b***3**, dielectric beam splitters may be employed.

According to some embodiments, each of color filters **430** includes a respective filter component (a static filter; not shown) and a respective shutter. Each filter component is configured to filter therethrough light in the respective APC. Each shutter is configured to be controllably opened and closed at command from control unit **408**, such that, when closed, the shutter prevents light from arriving at the respective filter component or blocks light transmitted through the respective filter component. According to some embodiments the shutters may be mechanically actuated.

Alternatively, according to some embodiments, each of the shutters may be an LCD panel, in which case, LSA **402** optics **410** may additionally include a linear polarizer (not shown) positioned between LSA **402** and CFA **404**.

According to some embodiments, both above and below first dichroic mirror **444***a***1**, and below each of second dichroic mirror **444***a***2** and third dichroic mirror **444***a***3**, first waveguide **440***a* may be coated with an anti-reflective coating. Similarly, above each of fourth dichroic mirror **444***b***1** and fifth dichroic mirror **444***b***2**, and above and below sixth dichroic **444***b***3**, second waveguide **440***b* may be coated with an anti-reflective coating. The anti-reflective coating may minimize undesirable reflections off the surfaces of waveguides **440**, thereby reducing loss of intensity.

According to some embodiments, and as depicted in FIG. **4**, second waveguide **440***b* may be joined at a boundary thereof to a LOE **40**, which corresponds to specific embodiments of LOE **10**. According to some alternative embodiments, second waveguide **440***b* may form a LOE, such as LOE **10**. Also indicated are beam splitters **42** embedded in an end portion (not numbered) of LOE **40**.

According to some alternative embodiments, instead of color filters **430**, filters without color filtering capabilities (e.g. shutters) may be employed, so that the APC filtering is implemented solely by dichroic mirrors **444**. According to other alternative embodiments, instead of color filters **430**, filters without color filtering capabilities may be employed, and, in addition, instead of dichroic mirrors **444**, diffraction gratings—having the same APC filtering properties as dichroic mirrors **444**—may be employed.

According to some embodiments, instead of using dichroic mirrors, or in addition to the use thereof, waveguides **440** may be coated by dichroic coatings to achieve the same color filtering. Additionally or alternatively, according to some embodiments, color filters **430** may be chromatic absorptive filters.

According to some embodiments, optics **410** includes a collimating lens **428** positioned between LSA **402** and CFA **404**.

Also shown in FIG. **4**A are trajectories of light rays (indicated by dashed arrows **401**, not all of which are numbered) from LSA **402**, (via collimating lens **428**) to first waveguide **440***a*.

FIG. **5**A schematically depicts an optical assembly **500**, according to some embodiments. Optical assembly **500** corresponds to specific embodiments of optical assembly **100**, wherein the CFA includes a color selective switch based on a liquid crystal on silicon (LCoS) array. Optical assembly **500** includes an LSA **502**, a CFA **504** including a LCoS array **520**, and a control unit **508**. Each of LSA **502**, CFA **504**, and control unit **508** corresponds to specific embodiments of LSA **102**, CFA **104**, and control unit **108**, respectively. According to some embodiments, and as depicted in FIG. **5**, optical assembly **500** further includes optics **510**, which corresponds to specific embodiments of optics **110**.

According to some embodiments, LSA **502** may be a LED array, such as an inorganic mLED array or an OLED array.

According to some embodiments, and as depicted in FIG. **5**A, optics **510** may include a polarizer **534**.

According to some embodiments, in addition to LCoS array **520**, CFA **504** may include a polarizing beam splitter (PBS) **550** and collimating optics **554** including a collimating mirror arrangement **556** and a quarter waveplate **558**. Collimating mirror arrangement **556** (shown for simplicity as including a single reflective element in FIG. **5**A) may include a plurality of curved mirrors and lenses and/or a Fresnel lens(es). PBS **550** includes a first face **552***a*, a second face **552***b*, a third face **552***c* opposite to first face **552***a*, and a fourth face **552***d* opposite to second face **552***b*. Polarizer **534** may be positioned between LSA **502** and first face **552***a*, so as to ensure that light—originating in LSA **502** and entering PBS **550**— is polarized. According to some embodiments, polarizer **534** is a linear polarizer. LCoS array **520** may be positioned opposite second face **552***b*. Quarter waveplate **558** may be positioned between fourth face **552***d* and collimating mirror arrangement **556**. As elaborated on below, in operation, light input into PBS **550**, via first face **552***a*, is output via third face **552***c*.

Referring also to FIG. **5**B, FIG. **5**B presents a schematic front view of LCoS array **520**, according to some embodiments. LCoS array **520** includes a plurality of cells **524**. Each of cells **524** may include one or more first sub-cells **524***a*, one or more second sub-cells **524***b*, and one or more one third sub-cells **524***c* corresponding to the first APC, second APC, and third APC, respectively. Sub-cells corresponding to the same color may be jointly on and off switchable by control unit **508**. When switched off, a sub-cell does not reflect any light impinging thereon. When switched on, a sub-cell reflects, or partially reflects, only light at the APC corresponding thereto. The degree of reflection, i.e. the percentage of the impinging light that is reflected, is controlled on an individual sub-cell basis by control unit **508**, as elaborated on below. Cells **524** and sub-cells **524***a*, **524***b*, and **524***c* may be arranged in any pattern known in the art of LCoS arrays.

Each of the light sources in LSA **502** may be configured to illuminate at least one cell from cells **524**. According to some such embodiments, of the light sources in LSA **502** may be configured to illuminate a plurality of cells from cells **524**, optionally, with each of cells **524** in LCoS array **520** being positioned to receive light only from, or substantially only from, a respective light source in LSA **502**. In particular, PBS **550** and collimating optics **554** may be configured such that light produced by LSA **502** is imaged on LCoS array **520**.

According to some embodiments, for each of the APCs, control unit **508** may be configured to send a pair of intensity maps: a lower-resolution intensity map to LSA **502** and a higher-resolution intensity map to LCoS array **520**. Thus, given image data in the form of three pairs of intensity maps corresponding to each of the three APCs, respectively, control unit **508** may be configured to successively send to LSA **102** and LCoS array **520** the three pairs of intensity maps. More precisely, control unit **508** may be configured to successively send the lower-resolution intensity maps to LSA **502** and the higher-resolution intensity maps to LCoS array **520** (with each pair of intensity maps being sent simultaneously or substantially simultaneously).

Each of the lower-resolution intensity maps constitutes a two-dimensional (spatial) intensity distribution that may specify per each of light sources **112** a respective intensity value. Each of the higher-resolution intensity maps constitutes a two-dimensional (spatial) intensity distribution that may specify per each of the sub-cells in LCoS array, which corresponds to the same APC as the lower-resolution intensity map, a respective intensity value.

More specifically, the reflection level of each sub-cell—that is, the percentage of light in the corresponding APC, which when impinging on the sub-cell, the sub-cell reflects—is dictated by the higher-resolution map corresponding to the same APC as the sub-cell. Thus, in contrast to optical assembly **200** (and optical assemblies **300** and **400**), wherein the resolution of the virtual images is determined by the density of the light sources in the LSA (e.g. the density of the inorganic mLEDs or OLEDs in the inorganic mLED or OLED array, respectively), in optical assembly **500**, the resolution of the virtual images is determined by the LCoS array (i.e. the density of the sub-cells therein).

Given a RGB color bitmap, that is, three intensity maps corresponding to each of the APCs, respectively, each pair of lower-resolution and higher-resolution intensity maps (in combination) reproduces the intensity map associated with the corresponding APC (as specified by the color bitmap). Consequently, by sufficiently rapidly actuating the light sources in LSA **502** and, in succession, sub-cells **524***a*, **524***b*, and **524***c* according to each of the pairs of the intensity maps, the generated illumination patterns—optionally, after passage through an output element, such as LOE **50**)—are effectively combined, so as to be perceivable by eye as a single color image (which the color bitmap encodes).

According to some embodiments, control unit **508** may be configured to decompose each of the three intensity maps of a RGB color bitmap into a pair of lower-resolution and higher-resolution intensity maps, as described above. Advantageously, according to some such embodiments, control unit **508** may include processing and memory components (e.g. a graphics processing unit) configured to decompose each of the three intensity maps of a RGB color bitmap such that overall power consumed in generating the associated illumination patterns is minimized or at least economized. Alternatively, according to some embodiments, control unit **508** may be configured to receive the three pairs of intensity maps from a computational unit, not included in optical assembly **500**, such as a processor of an AR NED, which includes optical assembly **500**. According to some such embodiments, the processor may be configured to decompose the three intensity maps of a RGB color bitmap such that overall power consumed in generating the associated illumination patterns is minimized or at least economized.

According to some embodiments, CFA **504** is switchable by control unit **508** between three transmission modes (or, equivalently, LCoS array **520** may be said to be switchable by control unit **508** between three reflection modes):

- In a first transmission mode, second sub-cells **524***b* and third sub-cells **524***c* are switched off, so that LCoS array **520** does not reflect any light in the second and third APCs. Each of first sub-cells **524***a* may be switched on to reflect a respective percentage of light incident thereon, as specified by the respective higher-resolution intensity map (i.e. corresponding to the first APC).
- In a second transmission mode, third sub-cells **524***c* and first sub-cells **524***a* are switched off, so that LCoS array **520** does not reflect any light in the third and first APCs. Each of second sub-cells **524***b* may be switched on to reflect a respective percentage of light incident thereon, as specified by the respective higher-resolution intensity map (i.e. corresponding to the second APC).
- In a third transmission mode, first sub-cells **524***a* and second sub-cells **524***b* are switched off, so that LCoS array **520** does not reflect any light in the first and second APCs. Each of third sub-cells **524***c* may be switched on to reflect a respective percentage of light incident thereon, as specified by the respective higher-resolution intensity map (i.e. corresponding to the third APC).

According to some embodiments, and as depicted in FIG. 5A, PBS **550** is composed of two prisms, which are joined at their bases. A surface **562** indicates the boundary between the bases. In operation, light rays **501**—generated by LSA **502** and with intensities dictated by a lower-resolution intensity map—may be polarized by polarizer **534** to form linearly polarized light rays **503**. Light rays **503** enter PBS **550** via first face **552***a*. Only one of light rays **503**, a light ray **503'**, is shown inside PBS **550**, but the following will be understood to apply to each of light rays **503**. Polarizer **534** is configured to pass light at a linear polarization such that on entry to PBS **550** and incidence on surface **562**, the light will be fully reflected. Consequently, light ray **503'** is fully reflected by surface **562**, as indicated by a reflected light ray **505'**. Light ray **505'** travels towards second face **552***b*, and is refracted thereby, as indicated by a refracted light ray **507'**.

Light ray **507'** is filtered, reflected, and has the polarization thereof rotated by 90° by one or more of the sub-cells in LCoS array **520** corresponding to the same APC as the lower-resolution intensity map according to which light rays **501** were generated. As compared to the intensity of light ray **507'** in the APC band, the intensity of the reflected light ray—a light ray **511'**— is attenuated by a factor dictated by the higher-resolution intensity map corresponding to the APC (i.e. the APC to which the lower-resolution intensity map corresponds). Light ray **511'** travels back towards second face **552***b* and is refracted on entry to PBS **550**. Due to the polarization thereof (90° rotated relative to the original polarization), the refracted light ray, i.e. a light ray **513'**, is fully transmitted across surface **562** travels towards fourth face **552***d*, and is refracted on exiting PBS **550**, as indicated by a refracted light ray **515'**. Light ray **515'** traverses quarter waveplate **558**, emerging therefrom as a circularly polarized light ray **517'**.

Light ray **517'** is reflected by collimating mirror arrangement **556**, as indicated by a reflected light ray **521'**. Light ray **521'** traverses quarter waveplate **558**, emerging therefrom as a linearly polarized light ray **523'** in the original linear polarization (i.e. the polarization as light rays **503**). Light ray **523'** enters PBS **550** via fourth face **552***d* and, due to the polarization thereof, is fully reflected by surface **562** and exits PBS **550** via third face **552***c*, as indicated by a reflected light ray **525'** and a refracted light ray **531'**.

Light ray **531'** constitutes one of light rays **531**. Each of light rays **531** can be "traced back" to one of light rays **501**, respectively.

Also indicated in FIG. **5**A are mirrors **52** and beam splitters **54** arranged on a first end-portion **56** and a second end-portion **58**, respectively, of LOE **50**, according to some embodiments. Mirrors **52** are configured to reflect light impinging thereon (e.g. light filtered through CFA **504**) towards beam splitters **54** in second end-portion **58**. Beam splitters **54** are configured to output the filtered light arriving thereat from first end-portion **56** together with ambient light, such as to output an AR image.

FIG. **6** schematically depicts an optical assembly **600**, according to some embodiments. Optical assembly **500** corresponds to specific embodiments of optical assembly **100**, wherein the CFA includes a color selective switch based on a liquid crystal on silicon (LCoS) array. Optical assembly **600** includes an LSA **602**, a CFA **604** including a LCoS array **620**, and a control unit **608**. Each of LSA **602**, CFA **604**, and control unit **608** corresponds to specific embodiments of LSA **102**, CFA **104**, and control unit **108**, respectively. According to some embodiments, and as depicted in FIG. **6**, optical assembly **600** further includes optics **610**, which corresponds to specific embodiments of optics **110**, and which may include a polarizer **634**.

Optical assembly **600** is similar to optical assembly **500** but differs therefrom at least in including two PBSs instead of a single PBS: A first PBS **670** and a second PBS **680**. A first collimating optics **674** includes a first collimating mirror arrangement **676** and a first quarter waveplate **678**, which are positioned in a similar manner relative to first PBS **670** as collimating mirror arrangement **556** and quarter waveplate **558** are positioned relative to PBS **550** of optical assembly **500**. Similarly, a second collimating optics **684** includes a second collimating mirror arrangement **686** and a second quarter waveplate **688**, which are positioned in a similar manner relative to second PBS **680** as collimating mirror arrangement **556** and quarter waveplate **558** are positioned relative to PBS **550** of optical assembly **500**.

First PBS **670** may include a first (top) face **672***a*, a second face **672***b* that may be perpendicular to first face **672***a*, a third face **672***c* opposite to the first face **672***a*, and a fourth face **672***d* opposite to second face **672***b*. First PBS **670** may further include an (inner) surface **692**, which may be similar to surface **562** of PBS **550**. Similarly, second PBS **680** may include a first (top) face **682***a*, a second face **682***b* that may be perpendicular to first face **682***a*, a third face **682***c* opposite to the first face **682***a*, and a fourth face **682***d* opposite to second face **682***b*. Second PBS **680** may further include an (inner) surface **694**, which may be similar to surface **562** of PBS **550**.

Polarizer **634** is positioned between LSA **602** and second face **682***b* of second PBS **680**. Polarizer **634** may be similar to polarizer **534**. According to some embodiments, polarizer **634** is a linear polarizer.

Second PBS **680** is positioned above first PBS **670** with third face **682***c* of second PBS **680** facing first face **672***a* of first PBS **670**.

A trajectory of a light ray **675**, according to some embodiments, is shown from its generation by LSA **602** to its output by second PBS **680**.

According to some embodiments, and as depicted in FIG. **6**, light generated by LSA **602** enters second PBS **680** via second face **682***b*, exits via fourth face **682***d*, is reflected by second collimating optics **684** and has its polarization rotated by 90°, before reentering second PBS **680**. The reentered light is reflected by second PBS **680** towards first PBS **670**, exits second PBS **680** via third face **682***c* and enters first PBS **670** via first face **672***a*. The light entered into first PBS **670** follows a similar trajectory to that depicted in FIG. **5**A.

According to some embodiments, second PBS **680** and second collimating optics **684** are configured such that light produced by LSA **602** is imaged (after passage via first PBS **670**) on LCoS array **620**.

Also indicated in FIG. **6** are mirrors **62** and beam splitters **64** arranged on the first end-portion and the second end-portion (not numbered), respectively, of LOE **60**, according to some embodiments and as described above with respect to LOE **50** of FIG. **5**A.

Methods

According to an aspect of some embodiments, there is provided a method for overlaying a virtual image on a real image in an AR NED. FIG. **7** presents a flowchart of such a method, a method **700**, according to some embodiments. Method **700** may include sequential implementation—per each of three intensity maps corresponding to the three APCs, respectively—stages of:

A stage **710** of actuating broadband white light sources in an LSA (such as the LSAs described above in the Systems subsection and LSAs similar thereto) of an optical assembly (such as the optical assemblies described above in the Systems subsection and optical assemblies similar thereto) of an AR NED according to the intensity map.

A stage **720** of selectively filtering light produced by the LSA into the corresponding APC by passing the light through a CFA (such as the CFAs described above in the Systems subsection and CFAs similar thereto) of the optical assembly.

A stage **730** of directing light, filtered through the CFA, into a LOE (such as the LOEs described above in the Systems subsection and LOEs similar thereto) of the AR NED.

According to some embodiments, the three intensity maps may be specified by a RGB color bitmap. According to some embodiments, stage **710** may be implemented using a LED array, such as an inorganic mLED array or an OLED array, essentially as detailed in the description of FIGS. **1**A and **1**B in the Systems subsection.

According to some embodiments, stage **720** may be implemented using a CFA, such as CFA **104**. According to some embodiments, stage **720** may be implemented using an LCD array, such as LCD array **220**, to selectively filter the light produced by the LSA, essentially as detailed in the description of FIGS. **2**A and **2**B in the Systems subsection. According to some embodiments, stage **720** may be implemented using a plurality of color filters, such as color filters **330** or color filters **430**, to selectively filter the light produced by the LSA, essentially as detailed in the description of FIGS. **3**A-**3**D or in the description of FIG. **4** in the Systems subsection. According to some embodiments, stage **720** may be implemented using a LCoS array, such as LCoS array **520** or LCoS array **620**, to selectively filter the light produced by the LSA, essentially as detailed in the description of FIGS. **5**A and **5**B or FIG. **6** in the Systems subsection.

According to some embodiments, operations of the LSA and the operations of the CFA may be synchronized using a control unit, such as control unit **108** (so as to ensure that when light sources in the LSA are actuated according to an intensity map corresponding to one of the APCs, the CFA filters therethrough light in the corresponding APC).

In stage **730**, the LOE may be configured to output the filtered light together with ambient light incident on the LOE, such that a (virtual) image formed by the filtered light is overlaid on a (real) image formed by the ambient light, essentially as described above in the Systems subsection with respect to LOE **10**.

Method **700** may be realized (i.e. implemented) using an AR NED including optical assembly **100**, any one of the specific embodiments thereof, i.e. optical assemblies **200**, **300**, **400**, **500**, and **600**, and optical assemblies similar thereof. Thus, when method **700** is realized using an AR NED including optical assembly **100** and LOE **10**, then stages **710**, **720**, and **730** are realized using LSA **102**, CFA **104**, control unit **108**, and LOE **10**. Similarly, when method **700** is realized using an AR NED including optical assembly **200** and LOE **20**, then stages **710**, **720**, and **730** are realized using LSA **202**, CFA **204**, control unit **208**, and LOE **20**, and so on with respect to AR NEDs including optical assembly

300 and a corresponding embodiment of LOE **10**, optical assembly **400** and LOE **40**, optical assembly **500** and LOE **50**, or optical assembly **600** and LOE **60**, respectively.

Optionally, according to some embodiments, method **700** may be configured for RGBW illumination. In such embodiments, method **700** may include a stage **740**. Stage **740** may be performed prior to the three implementations of the sequence of stages **710**, **720**, and **730**, after the three implementations, or even in between two of the implementations (e.g. in between the first implementation and the second implementation). According to some embodiments, stage **740** may include actuating the light sources in the LSA according to an additional intensity map, transmitting the produced light through the CFA without color filtering thereof, and directing the transmitted light to the LOE. Optionally, according to some alternative embodiments, the light produced by the additional intensity map may be guided directly to the LOE without having to pass through the CFA. The additional intensity map corresponds to white light.

More specifically, a RGB color bitmap specifies intensities $\{R_{ij}', G_{ij}', B_{ij}'\}_{i,j}$, wherein the indices i and j specify the position of the light source within the LSA (so that R_{ij}', G_{ij}', and B_{ij}' are red, green, and blue light intensities specified for the (i,j)-th light source). As a non-limiting example, according to some embodiments, corresponding RGBW intensity maps may specify, optionally, up to an overall multiplicative constant, $\{R_{ij}=R_{ij}'-W_{ij}, G_{ij}'=G_{ij}-W_{ij}, B_{ij}=B_{ij}'-W_{ij}, W_{ij}\}_{i,j}$. Here, for each pair i and j pair, the white light intensity map specifies the intensity $W_{ij}=\min(R_{ij}', G_{ij}', B_{ij}')$ with the minimum taken over the three intensities R_{ij}', G_{ij}', B_{ij}'.

According to some embodiments, method **700** may include consecutive implementations according to sequences of three intensity maps (or four intensity maps in embodiments including stage **740**), one sequence after the other, such that a stream of virtual images (a sequence of video images) is generated.

According to some embodiments, the CFA may include a first, second, and third type of filtering elements (cells or sub-cells), arranged in an array, and configured to filter light incident thereon into the first, second, and third APCs, respectively, with each of the filtering elements being individually addressable. More precisely, an intensity of light filtered by each filtering element may be controlled on an individual bases, as detailed, for example, with respect to optical assembly **500** in the description of FIGS. **5**A and **5**B in the Systems subsection. According to some such embodiments, method **700** may further include an initial preprocessing stage, wherein each of the three color intensity maps—specified by the RGB color bitmap—is respectively decomposed into a lower-resolution intensity map and a higher-resolution intensity map.

Each of the lower-resolution intensity maps specifies per each light source in the LSA (e.g. per each LED in the LED array) a respective intensity value. Each of the higher-resolution intensity maps specifies per each filtering element in the CFA, which corresponds to the same APC as the lower-resolution intensity map, a respective intensity value. Each pair of lower-resolution and higher-resolution intensity maps (in combination) reproduces the intensity map associated with the corresponding APC (as specified by the color bitmap).

It is appreciated that certain features of the disclosure, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the disclosure, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable sub-combination or as suitable in any other described embodiment of the disclosure. No feature described in the context of an embodiment is to be considered an essential feature of that embodiment, unless explicitly specified as such.

Although stages of methods according to some embodiments may be described in a specific sequence, methods of the disclosure may include some or all of the described stages carried out in a different order. A method of the disclosure may include a few of the stages described or all of the stages described. No particular stage in a disclosed method is to be considered an essential stage of that method, unless explicitly specified as such.

Although the disclosure is described in conjunction with specific embodiments thereof, it is evident that numerous alternatives, modifications, and variations that are apparent to those skilled in the art may exist. Accordingly, the disclosure embraces all such alternatives, modifications, and variations that fall within the scope of the appended claims. It is to be understood that the disclosure is not necessarily limited in its application to the details of construction and the arrangement of the components and/or methods set forth herein. Other embodiments may be practiced, and an embodiment may be carried out in various ways.

The phraseology and terminology employed herein are for descriptive purpose and should not be regarded as limiting. Citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the disclosure. Section headings are used herein to ease understanding of the specification and should not be construed as necessarily limiting.

What is claimed is:

1. An optical assembly for generating a color image using white light as source, the optical assembly comprising:
- a light source array (LSA) comprising a plurality of broadband white light sources;
- a color filter assembly (CFA); and
- a control unit;
- wherein the CFA comprises at least two waveguides, which are adjacently and successively disposed, and at least three filters disposed between the waveguides and/or embedded within the waveguides;
- wherein each of the waveguides has embedded therein at least two optical elements selected from at least one dichroic mirror, at least one beam splitting component, and/or at least one mirror;
- wherein a first waveguide of the at least two waveguides is configured to have transmitted thereinto light generated by the LSA;
- wherein the control unit is configured to actuate light sources in the LSA according to three intensity maps, each of the intensity maps corresponding to one of three additive primary color (APCs); and
- wherein the control unit is further configured to individually switch on and off each of the filters and synchronize the switching of the filters with operation of the LSA such that, when light sources in the LSA are actuated according to an intensity map corresponding to one of the APCs, the CFA filters therethrough light in the corresponding APC, which is output by a last waveguide of the at least two waveguides.

2. The optical assembly of claim **1**, wherein the LSA is a light emitting diode (LED) array.

3. The optical assembly of claim **2**, wherein the LED array is an inorganic micro-LED (mLED) array or an organic LED (OLED) array.

4. The optical assembly of claim 1, wherein the at least three filters comprise at least three color filters; and

wherein (i) at least one of the color filters is configured to, when switched on, filter therethrough light in a respective APC from the three APCs, and, when switched off, block all light arriving thereat, and/or (ii) at least one of the color filters is configured to, when switched on, block light in a respective APC from the three APCs, and, when switched off, block all light arriving thereat.

5. The optical assembly of claim 4, wherein the at least three color filters comprise a first color filter, a second color filter, and a third color filter configured to filter therethrough light in only one of the three APCs, respectively;

wherein the at least one dichroic mirror comprises at least three dichroic mirrors, each of the dichroic mirrors being configured to reflect or filter light in a respective APC from the three APCs;

wherein the first, second, and third color filters are disposed between the first waveguide and the last waveguide; and

wherein each of the dichroic mirrors is embedded within one of the waveguides, such that:

light generated by the LSA, and incident on a dichroic mirror, embedded in the first waveguide, is either directed thereby onto a respective one of the first, second, and third color filters or onto an adjacent dichroic mirror in the first waveguide; and

light filtered through any of the first, second, and third color filters, and incident on a dichroic mirror, embedded in the last waveguide, is reflected inside the second waveguide.

6. The optical assembly of claim 5, wherein the at least three dichroic mirrors comprise six dichroic mirrors, wherein a first dichroic mirror, a second dichroic mirror, and a third dichroic mirror, are embedded in a first side-portion, a central portion, and a second side-portion of the first waveguide, respectively, the central portion being disposed between the first and second side-portions of the first waveguide;

wherein a fourth dichroic mirror, a fifth dichroic mirror, and a sixth dichroic mirror, are embedded in a first side-portion, a central portion, and a second side-portion of the last waveguide, respectively, the central portion being disposed between the first and second side-portions of the last waveguide;

wherein the first, second, and third color filters are disposed between the first side-portions, the central portions, and the second side-portions, respectively; and

wherein the color filters and dichroic mirrors are configured such that when only the first color filter, only the second color filter, and only the third color filter, is switched on, light, generated by the LSA, and incident on the first side-portion of the first waveguide, is filtered into the first APC, the second APC, and the third APC, respectively, and is output at the second side-portion of the last waveguide.

7. The optical assembly of claim 4, wherein the at least two waveguides further comprise a second waveguide, which is disposed between the first waveguide and the last waveguide;

wherein the at least one beam splitting component comprises a first beam splitting component, a second beam splitting component, a third beam splitting component, and a fourth beam splitting component;

wherein the at least one mirror comprises a first mirror and a second mirror;

wherein the first waveguide has embedded, in a first side-portion thereof, the first beam splitting component, and, in a second side-portion thereof, the first mirror;

wherein the second waveguide has embedded, in a first side-portion thereof, the second beam splitting component, and, in a second side-portion thereof, the third beam splitting component;

wherein the last waveguide has embedded, in a first side-portion thereof, the second mirror, and, in a second side-portion thereof, the fourth beam splitting component;

wherein the first waveguide is configured to have transmitted thereinto the light generated by the LSA at the first side-portion thereof;

wherein the light filtered through the CFA is output from the second side-portion of the last waveguide; and

wherein each of the beam splitting components is a dichroic mirror, a diffraction grating, or a dielectric beam splitter.

8. The optical assembly of claim 7, wherein the at least three color filters comprise four color filters, with:

a first of the four color filters being disposed between the first side-portion of the first waveguide and the first side-portion of the second waveguide, or embedded within the first side-portion of the first waveguide;

a second of the four color filters being disposed between the second side-portion of the first waveguide and the second side-portion of the second waveguide, or embedded within the second side-portion of the first waveguide;

a third of the four color filters being disposed between the first side-portion of the second waveguide and the first side-portion of the last waveguide, or embedded within the first side-portion of the second waveguide; and

a fourth of the four color filters being disposed between the second side-portion of the second waveguide and the second side-portion of the last waveguide, or embedded within the second side-portion of the second waveguide; and

wherein APC filtering properties of each of the color filters, positionings thereof, and actuation times, are such that the first, second, and last waveguides propagate there across light in only one of first, second, and third APCs, respectively.

9. The optical assembly of claim 8, wherein:

when switched on, the first color filter blocks only light in the first APC;

when switched on, the second color filter filters therethrough only light in the first APC;

when switched on, the third color filter filters therethrough only light in the second APC; and

when switched on, the fourth color filter blocks only light in the second APC.

10. The optical assembly of claim 4, wherein at least one of the at least three color filters comprises a respective filter component and a respective shutter;

wherein the filter component is configured to transmit light only in the corresponding APC; and

wherein each shutter is configured to be controllably opened and closed at command from the control unit, such that, when closed, the shutter prevents light from arriving at the respective filter component or blocks light transmitted through the respective filter component.

11. The optical assembly of claim 10, wherein the optical assembly further comprises a linear polarizer, and at least

one of the shutters is an LCD panel, configured to be actuated by the control unit; and/or

wherein at least one of the shutters is a mechanical shutter.

12. The optical assembly of claim **1**, further comprising optics configured to direct light from the LSA onto the CFA, wherein the optics comprises one or more lenses configured to collimate light generated by the LSA.

13. The optical assembly of claim **1**, wherein the at least three filters comprise a first filter, a second filter, and a third filter, wherein each filter, when switched on, is open and transmits all light incident thereon, and, when switched off, is closed and blocks all light incident thereon;

wherein the at least one dichroic mirror comprises at least three dichroic mirrors, each of the dichroic mirrors being configured to reflect or filter light in a respective APC from the three APCs; and

wherein each of the dichroic mirrors is embedded within one of the waveguides, such that:

light generated by the LSA, and incident on a dichroic mirror, embedded in the first waveguide, is either directed thereby onto a respective one of the three filters or onto an adjacent dichroic mirror in the first waveguide; and

light filtered through any of the three filters and incident on a dichroic mirror, embedded in the last waveguide, is reflected inside the last waveguide.

14. The optical assembly of claim **13**, wherein the at least three dichroic mirrors comprise six dichroic mirrors, wherein a first dichroic mirror, a second dichroic mirror, and a third dichroic mirror, are embedded in a first side-portion, a central portion, and a second side-portion of the first waveguide, respectively, the central portion being disposed between the first and second side-portions of the first waveguide;

wherein a fourth dichroic mirror, a fifth dichroic mirror, and a sixth dichroic mirror, are embedded in a first side-portion, a central portion, and a second side-portion of the last waveguide, respectively, the central portion being disposed between the first and second side-portions of the last waveguide;

wherein the first, second, and third filters are disposed between the first side-portions, the central portions, and the second side-portions, respectively; and

wherein the filters and dichroic mirrors are configured such that when only the first filter, only the second filter, and only the third filter is open, light, generated by the LSA, and incident on the first side-portion of the first waveguide, is filtered into the first, second, and third APCs, respectively, and is output at the second side-portion of the last waveguide.

15. The optical assembly of claim **1**, wherein the at least three filters comprise a first filter, a second filter, a third filter, and a fourth filter, each filter, when switched on, is open and transmits all light incident thereon, and, when switched off, is closed and blocks all light incident thereon;

wherein the at least two waveguides further comprise a second waveguide, which is disposed between the first waveguide and the last waveguide;

wherein the at least one beam splitting component comprises a first beam splitting component, a second beam splitting component, a third beam splitting component, and a fourth beam splitting component;

wherein the at least one mirror comprises a first mirror, and a second mirror;

wherein the first waveguide has embedded, in a first side-portion thereof, a first beam splitting component, and, in a second side-portion thereof, a first mirror;

wherein the second waveguide has embedded, in a first side-portion thereof, a second beam splitting component, and, in a second side-portion thereof, a third beam splitting component;

wherein the last waveguide has embedded, in a first side-portion thereof, a second mirror, and, in a second side-portion thereof, a fourth beam splitting component;

wherein the first waveguide is configured to have transmitted thereinto the light generated by the LSA at the first side-portion thereof, and the light filtered through the CFA is output from the second side-portion of the last waveguide; and

wherein each of the beam splitting components is a dichroic mirror or a diffraction grating.

16. The optical assembly of claim **15**, wherein the first filter is disposed between the first side-portion of the first waveguide and the first side-portion of the second waveguide, or is embedded within the first side-portion of the first waveguide;

wherein the second filter is disposed between the second side-portion of the first waveguide and the second side-portion of the second waveguide, or is embedded within the second side-portion of the first waveguide;

wherein the third filter is disposed between the first side-portion of the second waveguide and the first side-portion of the last waveguide, or is embedded within the first side-portion of the second waveguide;

wherein the fourth filter is disposed between the second side-portion of the second waveguide and the second side-portion of the last waveguide, or is embedded within the second side-portion of the second waveguide; and

wherein the first dichroic mirror is configured to reflect only light in the first APC;

wherein the second dichroic mirror is configured to transmit only light in the third APC or reflect only light in the second APC;

wherein the third dichroic mirror is configured to transmit only light in the first APC or reflect only light in the second APC;

wherein the fourth dichroic mirror is configured reflect only light in the third APC; and

wherein the positionings of the four filters, and actuation times thereof, are such that the first, second, and last waveguides propagates there across light in only one of first, second, and third APCs, respectively.

17. The optical assembly of claim **1**, wherein the at least three intensity maps jointly constitute a color bitmap.

18. The optical assembly of claim **1**, wherein the control unit is further configured to successively actuate light sources in the LSA according to a plurality of groups of intensity maps, each group of intensity maps comprising at least three intensity maps corresponding to the three APCs, such that the light output by the optical assembly corresponds to a sequence of video frames.

19. The optical assembly of claim **1**, wherein the CFA is further configured to allow for controllable transmission therethrough of white light; and

wherein the control unit is further configured to actuate light sources in the LSA according to an additional intensity maps, corresponding to white light.

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